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Chapter 1 : Short essay on Aerobic and Anaerobic Respiration

Handbook of Fish Biology and Fisheries: v. 1 &; 2 - The Handbook of Fish Biology and reviews a broad variety of topics from evolutionary relationships and global biogeography to physiology Volume 17 (5), July.

However, fish can recruit a hypobranchial pump for active jaw occlusion during hypoxia, using feeding muscles innervated by anterior spinal nerves. This same pump is used to ventilate the air-breathing organ in air-breathing fishes. Some reptiles retain a buccal force pump for use during hypoxia or exercise. All vertebrates have respiratory rhythm generators RRG located in the brainstem. In cyclostomes and possibly jawed fishes, this may comprise elements of the trigeminal nucleus, though in the latter group RRG neurons have been located in the reticular formation. In air-breathing fishes and amphibians, there may be separate RRG for gill and lung ventilation. There is some evidence for multiple RRG in reptiles. Both amphibians and reptiles show episodic breathing patterns that may be centrally generated, though they do respond to changes in oxygen supply. Fish and larval amphibians have chemoreceptors sensitive to oxygen partial pressure located on the gills. Hypoxia induces increased ventilation and a reflex bradycardia and may trigger aquatic surface respiration or air-breathing, though these latter activities also respond to behavioural cues. Adult amphibians and reptiles have peripheral chemoreceptors located on the carotid arteries and central chemoreceptors sensitive to blood carbon dioxide levels. Lung perfusion may be regulated by cardiac shunting and lung ventilation stimulates lung stretch receptors. Vertebrates; Control of respiration; Respiratory rhythm generation; Water and air-breathing; Chemoreceptors; Mechanoreceptors Introduction There are important differences in the construction of the respiratory systems in ectothermic vertebrates, related to their modes of respiration. Fish typically propel water unidirectionally over the gills, using ventilatory muscles, which operate around the jaws and skeletal elements in the gill arches lining the pharynx. Adult amphibians retain the buccal force pump for tidal lung ventilation; their larvae are aquatic gill-breathers. Thus, in fish and amphibians the major respiratory muscles are cranial muscles, innervated by motor neurons with their cell bodies in the brainstem, located close to the presumed site of the central respiratory rhythm generator RRG. Reptiles retain an elaborate buccal, hyoidean force pump, but ventilate the lungs primarily with a thoracic aspiratory pump, although they typically lack the diaphragm, characteristic of mammals. The RRG in the brainstem generates respiratory activity in descending fibres that drive respiratory activity in spinal motor neurons innervating intercostal muscles Table 1 1. Mammals characteristically display continuous, rhythmic, aspiratory breathing to maintain their relatively high rates of oxygen uptake and carbon dioxide excretion. Exceptions are the foetus and neonate, which often show intermittent cycles of breathing related to sleep states 2 , and diving or hibernating mammals, which suspend or markedly reduce breathing and heart rates for varying periods but otherwise show typical cardiorespiratory control mechanisms. Patterns of ventilatory mechanics are defined solely in terms of the time spent in inspiration and expiration and the rate of air flow. Combinations of these variables produce the familiar components of breathing, namely, frequency, tidal volume and minute ventilation. Based on neurophysiological data, the mammalian ventilatory cycle has been divided into three distinct neural phases, defined as inspiration, post-inspiration passive expiration and expiration active expiration 3. The pattern is more complex in arrhythmic or episodic breathers, such as the amphibians and reptiles, where the components of breathing frequency also include an apnoeic or non-ventilatory period of variable duration and number of breaths per episode. Recordings from respiratory neurons in bullfrogs demonstrated that lower vertebrates also have a three-phase respiratory cycle. However, the first phase is expiration, and it occurs when the glottis opens. This is then followed by inspiration, which is produced by the brisk activation of the buccal elevators to push air back into the lungs. The last phase corresponds to the post-inspiratory phase in mammals and is a period of breath holding, during which neurons other than those involved in the production of the two other phases were shown to be active. The lungfish, which also have a buccal force pump, have a post-inspiratory phase 1. Figure 1 shows the respiratory cycle in a lizard related to activity in intercostal muscles. The cardiovascular system is not divided in a typical fish, with the heart delivering blood directly into the branchial vasculature and then on into the systemic circulation. In contrast, mammals and birds have a completely divided circulatory system, with separate pulmonary and systemic circuits. Air-breathing fish, amphibians and most reptiles have more or less incompletely divided circulatory systems, allowing differential perfusion of the pulmonary circuit. This ability may be an essential component of their intermittent patterns of ventilation, often associated with periods of submersion. Amphibians may, in addition, utilise bimodal respiration. Larval amphibians possess gills, often in combination with developing lungs, while adult amphibians can switch between cutaneous and lung breathing e. Despite these major differences in the construction and mode of operation of their respiratory and cardiovascular systems, evidence is accumulating that the vertebrates share some important similarities in the mechanisms of central generation of the respiratory rhythm, control of the cardiovascular system and in the central nervous and reflex generation of cardiorespiratory interactions. Knowledge of this complex area is dominated by the results of medically oriented research on mammals. Accordingly, this comparative review will consider control of the respiratory system, and its coordination with the cardiovascular system, in fish, amphibians and reptiles, in relation to our more thorough understanding of mammalian patterns. Reference will be made in the relevant sections to recent extensive reviews. Generation of the respiratory rhythm Despite years of detailed investigation, the nature of respiratory rhythm generation in all vertebrates, including mammals, is still in dispute with a role for pacemaker neurons showing spontaneous rhythmic oscillations contrasted with neural networks relying on synaptic interactions. What is not in dispute is the location of the RRG, which in all vertebrates is concentrated in the brainstem, and specifically the medulla oblongata. The mechanisms underlying respiratory rhythmogenesis in mammals are only now being resolved 1,4. These outflows probably derive, in an evolutionary sense, from the branchial motoneurons of more primitive, gill-breathing vertebrates, which retain their primary roles in respiratory rhythm generation in present-day fish and larval amphibians. Accordingly, the RF is thought to be the site both of the primary respiratory rhythm generator in fish and amphibians and of the respiratory and suckling rhythms in neonatal mammals. Cyclostomes Our understanding of the nature and topography of the RRG in fish can be traced back, in evolutionary terms, as far as the jawless cyclostomes. This group of vertebrates is composed of the jawless fishes, the myxinoids e. The lamprey Petromyzon sp has a larval form, the ammocoete, which has a muscular velum that pumps water and uses the pharyngeal clefts to filter feed. The feeding current is driven by muscular pumps associated with the velum and anterior branchial pouches that act against the elastic recoil of the branchial basket. The jawless adult has an oral sucker with which it attaches to fish such as the salmon. Consequently its mouth is closed off and the animal breathes via seven pairs of branchial pouches that are ventilated bidirectionally i. Ventilation is again by contraction of the muscles around the branchial basket forcing water out through the pouches, with elastic recoil drawing water back into the pouches. Generation of its respiratory rhythm has provided a model for what may be the ancestral form of the vertebrate RRG 4. Spontaneous bursts of respiration-related activity have been recorded from the isolated brainstem of the lamprey. Periodic bursts of activity recorded from motor nuclei supplying the Vth cranial nerve, located in the rostral half of the medulla, precede those recorded from respiratory motor nuclei in the caudal half of the medulla, innervating the VIIth, IXth and Xth cranial nerves 1,4. A brain-gill-velum preparation of the ammocoete larva showed that velar pumping was driven by an RRG in the trigeminal region with descending pathways driving the branchial motoneurons and this hierarchy is retained in the adult even though the trigeminal motoneurons are no longer active as the velum ceases to act as a pump. Activity continues in the trigeminal nucleus when it is isolated from the rest of the brain, suggesting that rhythm generation involves neurons located within this region. Recent evidence suggests that rhythm generation in these rostral neurons fits a "group pacemaker" model as their activity continues in an isolated brainstem, bathed with chloride-free saline 4. Electrical stimulation of this area excites the other respiratory motoneurons directly and could entrain the respiratory rhythm. These observations suggest that the motor pattern for respiration is at least partly generated and co-ordinated in the rostral half of the medulla in the lamprey, possibly in the trigeminal nucleus, and is transmitted to respiratory motoneurons through descending pathways 5. However, the caudal region of the brainstem, including the motor nuclei of the VIIth, IXth and Xth cranial nerves, is capable of generating rhythmic activity following transaction at the level of the Vth nucleus, suggesting a separate rhythm generator possibly responsible for strong contraction of the muscles of the gill pouches or "coughs" used to clear the branchial basket of obstruction. Midline transaction of the rostral medulla disrupts the normal respiratory rhythm while leaving the coughs unaffected 5. Although the true nature of the RRG remains unresolved, the mechanisms uncovered in the cyclostomes seem to be somewhat similar to those retained in jawed fishes, implying that they utilise a mechanism that may be an ancestral link back to velar ventilation of a feeding apparatus. Jawed fishes Because water contains less oxygen per unit volume than air and yet is considerably more dense and viscous, fish normally exhibit continuous rhythmical breathing movements of the buccal and septal or opercular pumps. Rhythmic ventilatory movements continue in fish following brain transection to isolate the medulla oblongata, though changes in pattern indicate that there are influences from higher centres. Central recording and marking techniques have identified a longitudinal strip of neurons with spontaneous respiration-related bursting activity. These neurons make up elements of the trigeminal Vth, facial VIIth, glossopharyngeal IXth, and vagal Xth motor nuclei, which drive the respiratory muscles, together with the descending trigeminal nucleus and the reticular formation. Areas in the midbrain have efferent and afferent connections with the reticular formation 1. The respiratory rhythm apparently originates in a diffuse respiratory pattern generator in the reticular formation, though maintenance of a respiratory rhythm in intact animals generally relies on an element of respiratory drive from peripheral receptors. Vagal afferents from the gill arches that innervate a range of tonically and physically active mechanoreceptors and chemoreceptors project to the motor nuclei via the intermediate facial nucleus 1. Simultaneous recordings of efferent activity from the central cut ends of the nerves innervating the respiratory muscles of the dogfish, and the pacu, revealed that the Vth cranial nerve fires in advance of the VIIth, IXth, and Xth cranial nerves 6,7. The resultant co-ordinated contractions of the appropriate respiratory muscles may relate to their original segmental arrangement before the evolution of the brain, head and jaws with their cranial musculature, an arrangement that is retained in the hindbrain of the dogfish in the sequential topographical arrangement of the motor nuclei, including the subdivisions of the vagal motor nucleus 6. This traditional view of the origin of the jaws and visceral arches and their innervation has recently been questioned on the basis of developmental studies of the role of neural crest cells. These suggest a separate origin for the jaws as feeding structures, independent of the visceral arches, which combined ventilation with filter-feeding, a view supported by study of marker genes. As suggested above, a possible evolutionary antecedent of the jaws may be the velum of filter feeding protochordates or larval cyclostomes. Fish often show markedly reduced ventilation rates when inactive in normoxic or hyperoxic waters and may interrupt their normal regular rhythm of gill ventilation and exhibit episodic breathing patterns. Carp were shown to possess a group of neurons with phase switching properties situated in the midbrain, that appear to play a key role in the control of episodic breathing. Stimulation of this area of the brainstem during a ventilatory pause brought forward the onset of the next breathing bout 1. Both elasmobranchs and teleosts can recruit an additional group of hypobranchial muscles into the respiratory cycle to provide active jaw occlusion. These are a complex ventral sheet of muscle, inserted between the pectoral girdle, the lower jaw and the ventral processes of the hyoid and branchial skeleton, associated primarily with suction feeding and ingestion in water-breathing fishes, recruited into the respiratory cycle during periods of vigourous, forced ventilation such as may occur following exercise or deep hypoxia Table 1 8. These muscles are innervated by the hypobranchial nerve, which contains elements of the occipital nerves and the anterior spinal nerves. Injection of adrenaline into the dogfish stimulates active ventilation and induces activity in the hypobranchial nerve of the dogfish 8. The hypobranchial nerve in fish is the morphological equivalent of the hypoglossal nerve, which innervates the muscles of the tongue in reptiles, birds and mammals. These muscles are utilised in suckling by infant mammals, an activity likely to require its own central oscillator, which is thought to reside in the RF. The RRG in fish is thought to reside in the RF, suggesting an evolutionary link from fish to mammals 1. Air-breathing fishes Air-breathing fishes have evolved a variety of air-breathing organs ABO for obtaining oxygen from above the water surface but retain gills, ventilated by cranial muscles, for the uptake of a variable proportion of their oxygen requirements, dependent on species and conditions, and for excretion of most of their carbon dioxide. Many facultative air-breathers, such as the tarpon, rely on gill ventilation and restrict blood flow to the ABO in normoxic water but increase rates of air-breathing and perfusion of the ABO with hypoxic exposure and particularly during exercise 9. During these periods opercular beating becomes imperceptible, indicating cessation of effective gill breathing or a switch to ram ventilation whilst swimming. Access to air reduces the lactic acid load during burst swimming and prolongs aerobic exercise in tarpon but they are able to repay an accumulated oxygen debt during recovery by increased rates of gill ventilation In all air-breathing fish, gulping of air at the water surface is achieved through the action of the same muscles as used for feeding or for forced ventilation in water-breathing fishes. These are elements of the jaw musculature, innervated by cranial nerve V, together with the hypobranchial musculature, innervated by occipital and anterior spinal nerves Table 1. They function together in a co-ordinated action either for feeding or gulping air, actions that are independent of the visceral arches and may derive from their separate evolutionary origins as feeding muscles. In the primitive ray-finned actinopterygian fish, the bowfin Amia calva , that utilises a well-vascularized swimbladder as an ABO, there appear to be two types of airbreath, one that involves exhalation followed by inhalation designated "type I" airbreaths and one that simply involves inhalation "type II" airbreaths. It is suggested that type I breaths are respiratory in nature whereas type II breaths have a buoyancy-regulating function. Spectral analysis indicates that there is an inherent rhythmicity to "type I" i. This periodicity may be driven by changes in blood O2 status that occur during the interbreath interval, rather than by an RRG for air-breathing. Some authors have suggested that air-breathing is critically dependent on afferent feedback and, as stated above, is simply a reorganisation of coughing and suction feeding movements requiring relatively little neural reorganisation 4, Control of the switch between ventilation of the gills and the ABO is likely to relate to stimulation of chemoreceptors by reduced oxygen levels at the gills or in the ABO but the central sites responsible for control of air-breathing reflexes in fish are still unknown. Reorganisation of the central nervous system CNS associated with the evolution of air-breathing has been poorly studied in fish.

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Chapter 2 : Fish Respiration (Fish Physiology, Volume 17) - PDF Free Download

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Set your stopwatch for one minute, and count the number of times the smaller fish breathes in one minute. You can watch how many times the operculum flaps or how many times the mouth opens, but be consistent. Repeat three times, then calculate the average. Set the stopwatch again and do the same for the larger fish. Pour it into the bowl containing the smaller fish, and for the next minute, measure its breathing. Do the same to the bowl containing the larger fish. Place a thermometer in the containerand write down the temperature. Add ice cubes to the container. Repeat steps 4 through 8 with the other fish. Plot your findings on a line graph. Results Fish breathe more in warm water. They also breathe more when they get excited or scared by water flowing into their bowl. Breathing is the process of moving air in and out of the lungs using breathing organs. You breathe through your mouth or nose. Fish breathe through gills, which are hidden underneath the operculum. Respiration is what happens when you move oxygen from your environment and into your cells. Carbon dioxide comes out of the cells and into the environment. In animals, the actual exchange of gases occurs in tiny blood vessels called capillaries. Do you breathe more at different times? Just like us, bony fish use their operculum to change the way water flows over their gills. They can change how quickly they breathe as well. As the water is poured into their bowl, the fish move around more. Metabolism refers to the chemical processes in the body that help an animal live. Small animals are often in more danger of being eaten, so they need to move and process energy quickly. What happened when you chilled the water? They breathe less frequently in cooler water. Disclaimer and Safety Precautions Education. In addition, your access to Education. Warning is hereby given that not all Project Ideas are appropriate for all individuals or in all circumstances. Implementation of any Science Project Idea should be undertaken only in appropriate settings and with appropriate parental or other supervision. Reading and following the safety precautions of all materials used in a project is the sole responsibility of each individual. Related learning resources Workbook Aquatic Biomes Dive into earth and life science with this book on aquatic biomes. Research reefs, learn wetland animals, and explore the squishy world of swamps in this book about these wet and wild ecosystems.

Chapter 3 : Gill - Wikipedia

Carbon dioxide is also generated by cellular metabolism and must be removed from the cell. There must be an exchange of gases: Animals have organ systems involved in facilitating this exchange as well as the transport of gases to and from exchange areas. Bodies and Respiration Back to Top Single-celled organisms exchange gases directly across their cell membrane. However, the slow diffusion rate of oxygen relative to carbon dioxide limits the size of single-celled organisms. Simple animals that lack specialized exchange surfaces have flattened, tubular, or thin shaped body plans, which are the most efficient for gas exchange. However, these simple animals are rather small in size. Respiratory Surfaces Back to Top Large animals cannot maintain gas exchange by diffusion across their outer surface. They developed a variety of respiratory surfaces that all increase the surface area for exchange, thus allowing for larger bodies. A respiratory surface is covered with thin, moist epithelial cells that allow oxygen and carbon dioxide to exchange. Those gases can only cross cell membranes when they are dissolved in water or an aqueous solution, thus respiratory surfaces must be moist. Methods of Respiration Back to Top Sponges and jellyfish lack specialized organs for gas exchange and take in gases directly from the surrounding water. Flatworms and annelids use their outer surfaces as gas exchange surfaces. Arthropods, annelids, and fish use gills; terrestrial vertebrates utilize internal lungs. Gas exchange systems in several animals. Images from Purves et al. The Body Surface Flatworms and annelids use their outer surfaces as gas exchange surfaces. Earthworms have a series of thin-walled blood vessels known as capillaries. Gas exchange occurs at capillaries located throughout the body as well as those in the respiratory surface. Amphibians use their skin as a respiratory surface. Frogs eliminate carbon dioxide 2. Constraints of water loss dictate that terrestrial animals must develop more efficient lungs. Gills Gills greatly increase the surface area for gas exchange. They occur in a variety of animal groups including arthropods including some terrestrial crustaceans , annelids, fish, and amphibians. Gills typically are convoluted outgrowths containing blood vessels covered by a thin epithelial layer. Typically gills are organized into a series of plates and may be internal as in crabs and fish or external to the body as in some amphibians. Gills are very efficient at removing oxygen from water: Water flows over gills in one direction while blood flows in the opposite direction through gill capillaries. This countercurrent flow maximizes oxygen transfer. Countercurrent flow in a fish. Tracheal Systems Many terrestrial animals have their respiratory surfaces inside the body and connected to the outside by a series of tubes. Tracheae are these tubes that carry air directly to cells for gas exchange. Spiracles are openings at the body surface that lead to tracheae that branch into smaller tubes known as tracheoles. Body movements or contractions speed up the rate of diffusion of gases from tracheae into body cells. However, tracheae will not function well in animals whose body is longer than 5 cm. Respiratory system in an insect. Image from Purves et al. Lungs Lungs are ingrowths of the body wall and connect to the outside by as series of tubes and small openings. Lung breathing probably evolved about million years ago. Lungs are not entirely the sole property of vertebrates, some terrestrial snails have a gas exchange structures similar to those in frogs. Lungs in a bird top and amphibian bottom. Respiratory System Principles Back to Top Movement of an oxygen-containing medium so it contacts a moist membrane overlying blood vessels. Diffusion of oxygen from the medium into the blood. Transport of oxygen to the tissues and cells of the body. Diffusion of oxygen from the blood into cells. Carbon dioxide follows a reverse path. Functional unit of a mammalian lung. The Human Respiratory System Back to Top This system includes the lungs, pathways connecting them to the outside environment, and structures in the chest involved with moving air in and out of the lungs. The human respiratory system. Air enters the body through the nose, is warmed, filtered, and passed through the nasal cavity. Air passes the pharynx which has the epiglottis that prevents food from entering the trachea. The upper part of the trachea contains the larynx. The vocal cords are two bands of tissue that extend across the opening of the larynx. After passing the larynx, the air moves into the bronchi that carry air in and out of the lungs. The lungs and alveoli and their relationship to the diaphragm and capillaries. Bronchi are reinforced to prevent their collapse and are lined with ciliated epithelium and mucus-producing cells. Bronchi branch into smaller and smaller tubes known as bronchioles. Bronchioles terminate in grape-like sac clusters known as alveoli. Alveoli are surrounded by a network of thin-walled capillaries. Gas exchange across capillary and alveolus walls. The lungs are large, lobed, paired organs in the chest also known as the thoracic cavity. Thin sheets of epithelium pleura separate the inside of the chest cavity from the outer surface of the lungs. The bottom of the thoracic cavity is formed by the diaphragm. Ventilation is the mechanics of breathing in and out. When you inhale, muscles in the chest wall contract, lifting the ribs and pulling them, outward. The diaphragm at this time moves downward enlarging the chest cavity. Reduced air pressure in the lungs causes air to enter the lungs. Exhaling reverses theses steps. Diseases of the Respiratory System Back to Top The condition of the airways and the pressure difference between the lungs and atmosphere are important factors in the flow of air in and out of lungs. Many diseases affect the condition of the airways. Asthma narrows the airways by causing an allergy-induced spasms of surrounding muscles or by clogging the airways with mucus. Bronchitis is an inflammatory response that reduces airflow and is caused by long-term exposure to irritants such as cigarette smoke, air pollutants, or allergens. Cystic fibrosis is a genetic defect that causes excessive mucus production that clogs the airways. The Alveoli and Gas Exchange Back to Top Diffusion is the movement of materials from a higher to a lower concentration. The differences between oxygen and carbon dioxide concentrations are measured by partial pressures. The greater the difference in partial pressure the greater the rate of diffusion. Respiratory pigments increase the oxygen-carrying capacity of the blood. Humans have the red-colored pigment hemoglobin as their respiratory pigment. Hemoglobin increases the oxygen-carrying capacity of the blood between 65 and 70 times. Each red blood cell has about million hemoglobin molecules, and each milliliter of blood contains 1. Effectiveness of various oxygen carrying molecules. Carbon dioxide concentration in metabolically active cells is much greater than in capillaries, so carbon dioxide diffuses from the cells into the capillaries. Water in the blood combines with carbon dioxide to form bicarbonate. This removes the carbon dioxide from the blood so diffusion of even more carbon dioxide from the cells into the capillaries continues yet still manages to "package" the carbon dioxide for eventual passage out of the body. Details of gas exchange. In the alveoli capillaries, bicarbonate combines with a hydrogen ion proton to form carbonic acid, which breaks down into carbon dioxide and water. The carbon dioxide then diffuses into the alveoli and out of the body with the next exhalation. Control of Respiration Back to Top Muscular contraction and relaxation controls the rate of expansion and constriction of the lungs. These muscles are stimulated by nerves that carry messages from the part of the brain that controls breathing, the medulla. Two systems control breathing: Both are involved in holding your breath. Although the automatic breathing regulation system allows you to breathe while you sleep, it sometimes malfunctions. Apnea involves stoppage of breathing for as long as 10 seconds, in some individuals as often as times per night. This failure to respond to elevated blood levels of carbon dioxide may result from viral infections of the brain, tumors, or it may develop spontaneously. A malfunction of the breathing centers in newborns may result in SIDS sudden infant death syndrome. As altitude increases, atmospheric pressure decreases. Above 10, feet decreased oxygen pressures causes loading of oxygen into hemoglobin to drop off, leading to lowered oxygen levels in the blood. The result can be mountain sickness nausea and loss of appetite. Mountain sickness does not result from oxygen starvation but rather from the loss of carbon dioxide due to increased breathing in order to obtain more oxygen.

Chapter 4 : Chapter 21 Aeration and Oxygenation in Aquaculture

Fish Physiology: The Physiology of Tropical Fishes, Volume 21 Fish Physiology: The Physiology of Polar Fishes, Volume 22 Fish Physiology: Fish Biomechanics, Volume

Firstly they have different life styles, obviously a fish that spends most of its life resting on the bottom of the ocean waiting for its dinner to swim by needs less O2 than a fish which actively chases smaller fish for its dinner. However most of the problem is solved in the design of the gills. In fish there is a bony plate protecting the gills, this is called the operculum, and it is hinged and has muscles attached to it so it can be regularly opened and closed. This ability to have water continually passing over the gills is one of the major factors making gills more efficient than lungs. With lungs the air comes in, fills the space, and then has to be expelled before any more O2 rich air can be brought in. In sharks and rays the number of gills is usually 5, but there are some species with 6 or 7 sets, in fish the number of gills is 4 on either side of the body. Each gill is supported by a gill arch and protected by gill rakers. Each gill arch supports one set of paired gill filaments. The gill rakers help make sure that no extraneous material gets into the gill filaments to clog them up. Each paired gill filament in turn supports numerous lamellae sing. The lamellae are very fine structures, however there exact dimensions depend on the normal activity levels of the fish in question. The more active the fish the thinner they are and the less distance there is between them. The presence of all these lamellae greatly increases the surface area of the gills, meaning that a large amount of water is available for gaseous exchange at any particular moment of time. In active fish, such as the Atlantic Mackerel Scomber scombrus , which has nearly the same gill dimensions as the Atlantic Herring, there may be as much as 1, square mm of lamellae surface for every gram of body weight. Such a fish weighing 1 kg will have approximately 1 square metre of gill surface area. Having such a large amount of gill area obviously helps the fish in its battle to extract enough O2 from the water it lives in. The Lamellae are basically collections of blood vessels sandwiched between two sets of membranes. The membranes keep the blood and the water separate whilst allowing the dissolved gases, O2 and CO2, to diffuse naturally from one liquid to the other, depending on which has the greater concentration of either gas. The laws of physics compel gases to seek equilibrium, if you have different concentrations of a particular gas on either side of a permeable membrane i. To ensure a continuous gradient of gaseous difference between its blood and the water flowing past its gills fish use a counter-current system. This means that the blood flows along the vessels in the lamellae in the opposite direction to which the water is passing on the outside of the lamellae. While it may not seem entirely intuitive that a counter-current system is much more effective than a system in which the both fluids flow side by side in the same direction, scientists have tested the system by artificially controlling the water flow, and they have found that it is in fact five times more efficient. The system works because the blood enters the gills as the water is leaving them, at this point both of them have their lowest O2 and highest CO2 concentrations, conversely, the blood leaves the gills as the water is entering them, at which point both have their highest O2 and lowest CO2 concentrations. Thus the difference remains, and O2 moves out of the water and into the blood during the whole operation. Fish can breathe the water by swimming forwards and letting some of the passing water flow in through the mouth, across the gills, and then out. They can control the amount of blood flowing through their gills, increasing the amount of oxygen they take from the water if they being more active. When they are moving slowly, or resting in the water fish can breathe the water by synchronously expanding and contracting the buccal cavity the mouth and throat , and the opercular cavity, which is the space behind the operculum where the gills are. In doing this they can pump a continuous stream of water across their gills. Sharks do not have an operculum, or an opercular cavity, but have instead a branchial cavity and a series of branchial flaps, one for each set of gill but which work in a similar way. Sharks also have a pair of spiracles in front of their gills one on each side , they can pump water in through these spiracles and over their gills. Most fish can also absorb some O2 through their skin, and while they are in their larval form this is often the main source of respiration.

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Chapter 5 : Control of respiration in fish, amphibians and reptiles

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History[edit] Galen observed that fish had multitudes of openings foramina , big enough to admit gases, but too fine to give passage to water. Pliny the Elder held that fish respired by their gills, but observed that Aristotle was of another opinion. However, more complex or more active aquatic organisms usually require a gill or gills. Many invertebrates, and even amphibians, use both the body surface and gills for gaseous exchange. The delicate nature of the gills is possible because the surrounding water provides support. The blood or other body fluid must be in intimate contact with the respiratory surface for ease of diffusion. A cubic meter of air contains about grams of oxygen at STP. The concentration of oxygen in water is lower than in air and it diffuses more slowly. The density of the water prevents the gills from collapsing and lying on top of each other, which is what happens when a fish is taken out of water. In fish and some molluscs, the efficiency of the gills is greatly enhanced by a countercurrent exchange mechanism in which the water passes over the gills in the opposite direction to the flow of blood through them. Most species employ a countercurrent exchange system to enhance the diffusion of substances in and out of the gill, with blood and water flowing in opposite directions to each other. The gills are composed of comb-like filaments, the gill lamellae, which help increase their surface area for oxygen exchange. Then it draws the sides of its throat together, forcing the water through the gill openings, so it passes over the gills to the outside. Fish gill slits may be the evolutionary ancestors of the tonsils , thymus glands , and Eustachian tubes , as well as many other structures derived from the embryonic branchial pouches. Fish gill The gills of fish form a number of slits connecting the pharynx to the outside of the animal on either side of the fish behind the head. Originally there were many slits, but during evolution, the number reduced, and modern fish mostly have five pairs, and never more than eight. Adjacent slits are separated by a cartilaginous gill arch from which projects a cartilaginous gill ray. This gill ray is the support for the sheet-like interbranchial septum , which the individual lamellae of the gills lie on either side of. The base of the arch may also support gill rakers , projections into the pharyngeal cavity that help to prevent large pieces of debris from damaging the delicate gills. This bears a small pseudobranch that resembles a gill in structure, but only receives blood already oxygenated by the true gills. In slow-moving or bottom-dwelling species, especially among skates and rays, the spiracle may be enlarged, and the fish breathes by sucking water through this opening, instead of through the mouth. The remaining slits are covered by an operculum , developed from the septum of the gill arch in front of the first gill. The great majority of bony fish species have five pairs of gills, although a few have lost some over the course of evolution. The operculum can be important in adjusting the pressure of water inside of the pharynx to allow proper ventilation of the gills, so bony fish do not have to rely on ram ventilation and hence near constant motion to breathe. Valves inside the mouth keep the water from escaping. Some species retain gill rakers. Though all but the most primitive bony fish lack spiracles, the pseudobranch associated with them often remains, being located at the base of the operculum. This is, however, often greatly reduced, consisting of a small mass of cells without any remaining gill-like structure. Salt water is less dilute than these internal fluids, so saltwater fish lose large quantities of water osmotically through their gills. To regain the water, they drink large amounts of sea water and excrete the salt. Fresh water is more dilute than the internal fluids of fish, however, so freshwater fish gain water osmotically through their gills. Instead, the gills are contained in spherical pouches, with a circular opening to the outside. Like the gill slits of higher fish, each pouch contains two gills. In some cases, the openings may be fused together, effectively forming an operculum. Lampreys have seven pairs of pouches, while hagfishes may have six to fourteen, depending on the species. In the hagfish, the pouches connect with the pharynx internally and a separate tube which has no respiratory tissue the pharyngocutaneous duct develops beneath the pharynx proper, expelling ingested debris by closing a valve at its anterior end. Usually no spiracle or true operculum is present, though many species have operculum-like structures. Instead of internal gills, they develop three feathery external gills that grow from the outer surface of the gill arches. Sometimes, adults retain these, but they usually disappear at metamorphosis. Examples of salamanders that retain their external gills upon reaching adulthood are the olm and the mudpuppy. Still, some extinct tetrapod groups did retain true gills. A study on Archegosaurus demonstrates that it had internal gills like true fish. The gill or ctenidium is visible in this view of the right-hand side of the animal. Crustaceans , molluscs , and some aquatic insects have tufted gills or plate-like structures on the surfaces of their bodies. Gills of various types and designs, simple or more elaborate, have evolved independently in the past, even among the same class of animals. The segments of polychaete worms bear parapodia many of which carry gills. In some crustaceans these are exposed directly to the water, while in others, they are protected inside a gill chamber. A current of water is maintained through the gills for gas exchange, and food particles are filtered out at the same time. These may be trapped in mucus and moved to the mouth by the beating of cilia. These thin protuberances on the surface of the body contain diverticula of the water vascular system. Caribbean hermit crabs have modified gills that allow them to live in humid conditions. The gills of aquatic insects are tracheal , but the air tubes are sealed, commonly connected to thin external plates or tufted structures that allow diffusion. The oxygen in these tubes is renewed through the gills. In the larval dragon fly , the wall of the caudal end of the alimentary tract rectum is richly supplied with tracheae as a rectal gill, and water pumped into and out of the rectum provides oxygen to the closed tracheae. Plastrons[edit] A plastron is a type of structural adaptation occurring among some aquatic arthropods primarily insects , a form of inorganic gill which holds a thin film of atmospheric oxygen in an area with small openings called spiracles that connect to the tracheal system. The plastron typically consists of dense patches of hydrophobic setae on the body, which prevent water entry into the spiracles, but may also involve scales or microscopic ridges projecting from the cuticle. The physical properties of the interface between the trapped air film and surrounding water allow gas exchange through the spiracles, almost as if the insect were in atmospheric air. Carbon dioxide diffuses into the surrounding water due to its high solubility , while oxygen diffuses into the film as the concentration within the film has been reduced by respiration , and nitrogen also diffuses out as its tension has been increased. Oxygen diffuses into the air film at a higher rate than nitrogen diffuses out. However, water surrounding the insect can become oxygen-depleted if there is no water movement , so many such insects in still water actively direct a flow of water over their bodies. The inorganic gill mechanism allows aquatic insects with plastrons to remain constantly submerged. Examples include many beetles in the family Elmidae , aquatic weevils , and true bugs in the family Aphelocheiridae , as well as at least one species of ricinuleid arachnid. Other diving insects such as backswimmers , and hydrophilid beetles may carry trapped air bubbles, but deplete the oxygen more quickly, and thus need constant replenishment.

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Chapter 6 : The Earth Life Web, Fish Gills & Respiration

FISH RESPIRATION This is Volume 17 in the FISH PHYSIOLOGY series Edited by Steve F. Perry and Bruce L. Tufts A complete list of books in this series appears at the end of the volume.

How Do Fish Breathe? Respiration in fish or in that of any organism that lives in the water is very different from that of human beings. Organisms like fish, which live in water, need oxygen to breathe so that their cells can maintain their living state. To perform their respiratory function, fish have specialized organs that help them inhale oxygen dissolved in water. Respiration in Fish Respiration in fish takes with the help of gills. Most fish possess gills on either side of their head. Gills are tissues made up of feathery structures called gill filaments that provide a large surface area for gas exchange. A large surface area is crucial for gas exchange in aquatic organisms as water contains very little amount of dissolved oxygen. The filaments in fish gills are arranged in rows in the gill arch. Each filament contains lamellae, which are discs supplied with capillaries. Blood enters and leaves the gills through these small blood vessels. Although gills in fish occupy only a small section of their body, the immense respiratory surface created by the filaments provides the whole organism with an efficient gas exchange. Fish take in oxygen-rich water through their mouths and pump it over their gills. As water passes over the gill filaments, blood inside the capillary network picks up the dissolved oxygen. The circulatory system then transports the oxygen to all body tissues and ultimately to the cells. While picking up carbon dioxide, which is removed from the body through the gills. After the water flows through the gills, it exits the body of the fish through the openings in the sides of the throat or through the operculum, a flap, usually found in bony fish, that covers and protects the fish gills. Some fish, like sharks and lampreys, possess multiple gill openings. However, bony fish like Rohu, have a single gill opening on each side. Practise This Question The openings shown in the above figure help the caterpillar breathe. What are they called?

Chapter 7 : How Do Fish Breathe Underwater? | Wonderopolis

Fish Respiration synthesizes classical literature and highlights recent developments pertaining to the respiratory physiology of fishes. Compiled by a team of international researchers, this comprehensive and authoritative review of the respiratory physiology of fishes will appeal to any comparative physiologist interested in this subject.

Fish respiration In most fish respiration takes place through gills. Lungfish , however, possess one or two lungs. The labyrinth fish have developed a special organ that allows them to take advantage of the oxygen of the air, but is not a true lung. Fish use the process known as countercurrent flow, in which water and blood flow in opposite directions across the gills, maximizing the diffusion of oxygen. Respiratory system of gastropods Molluscs generally possess gills that allow exchange of oxygen from an aqueous environment into the circulatory system. These animals also possess a heart that pumps blood which contains hemocyaninine as its oxygen-capturing molecule. Therefore, this respiratory system is similar to that of vertebrate fish. The respiratory system of gastropods can include either gills or a lung. Others may breathe atmospheric air while remaining submerged, via breathing tubes or trapped air bubbles, though some aquatic insects may remain submerged indefinitely and respire using a plastron. A very few Arachnids have adopted an aquatic life style including the Diving bell spider. In all cases, oxygen is provided from air trapped by hairs around the animals body. Aquatic reptiles[edit] All aquatic reptiles breathe air into lungs. The anatomical structure of the lungs is less complex in reptiles than in mammals , with reptiles lacking the very extensive airway tree structure found in mammalian lungs. Gas exchange in reptiles still occurs in alveoli however, reptiles do not possess a diaphragm. Thus, breathing occurs via a change in the volume of the body cavity which is controlled by contraction of intercostal muscles in all reptiles except turtles. In turtles, contraction of specific pairs of flank muscles governs inspiration or expiration. The skin of these animals is highly vascularized and moist, with moisture maintained via secretion of mucus from specialized cells. The lungs of birds also do not have the capacity to inflate as birds lack a diaphragm and a pleural cavity. Gas exchange in birds occurs between air capillaries and blood capillaries , rather than in alveoli. See Avian respiratory system for a detailed description of these and other features. Gills[edit] Posterior view of the gills of a tuna Many aquatic animals have developed gills for respiration which are specifically adapted to their function. In fish, for example, they have: In fish, the long bony cover for the gill the operculum can be used for pushing water. Some fish pump water using the operculum. Without an operculum, other methods, such as ram ventilation , are required. Some species of sharks use this system. When they swim, water flows into the mouth and across the gills. Because these sharks rely on this technique, they must keep swimming in order to respire. Bony fish use countercurrent flow to maximize the intake of oxygen that can diffuse through the gill. Countercurrent flow occurs when deoxygenated blood moves through the gill in one direction while oxygenated water moves through the gill in the opposite direction. This mechanism maintains the concentration gradient thus increasing the efficiency of the respiration process as well and prevents the oxygen levels from reaching an equilibrium. Cartilaginous fish do not have a countercurrent flow system as they lack bones which are needed to have the opened out gill that bony fish have. Control of respiration[edit] Scientists have investigated what part of the body is responsible for maintaining the respiratory rhythm. They found that neurons located in the brainstem of fish are responsible for the genesis of the respiratory rhythm. In both aquatic and terrestrial respiration, the exact mechanisms by which neurons can generate this involuntary rhythm are still not completely understood see Involuntary control of respiration. Another important feature of the respiratory rhythm is that it is modulated to adapt to the oxygen consumption of the body. The mechanisms by which these changes occur have been strongly debated over more than years between scientists. Those who think that the major part of the respiratory changes are pre-programmed in the brain, which would imply that neurons from locomotion centers of the brain connect to respiratory centers in anticipation of movements. Those who think that the major part of the respiratory changes result from the detection of muscle contraction, and that respiration is adapted as a consequence of muscular contraction and oxygen consumption. This would imply that the brain possesses some kind of detection mechanisms that would trigger a respiratory response when muscular contraction occurs.

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Chapter 8 : Comparative Vertebrate Anatomy - Respiration

Respiration in fish or in that of any organism that lives in the water is very different from that of human beings. Organisms like fish, which live in water, need oxygen to breathe so that their cells can maintain their living state.

So far we have studied that respiration takes place in the presence of oxygen of air. Respiration can, however, also take place in the absence of oxygen of air , though it is very rare. This means that oxidation of food to obtain energy can occur in the presence of oxygen as well as in the absence of oxygen. Based on this, we have two types of respiration: The respiration which uses oxygen is called aerobic respiration. In aerobic respiration, the glucose food is completely broken down into carbon dioxide and water by oxidation. Aerobic respiration produces a considerable amount of energy for use by the organism which gets stored in the ATP molecules. The breaking down of glucose food during aerobic respiration which is carried out by most of the organisms can be represented. We will study this in higher classes. All the organisms which obtain energy by aerobic respiration cannot live without oxygen of air. This is because if there is no oxygen, they cannot get energy from the food which they eat. Mitochondria are the sites of aerobic respiration in the cells. Thus, the breakdown of pyruvate to give carbon dioxide, water and energy takes place in mitochondria. The energy released during aerobic respiration is used by the organism. Most of the living organisms carry out aerobic respiration by using oxygen of air. For example, humans man , dogs, cats, lions, elephants, cows, buffaloes, goat, deer, birds, lizards, snakes, earthworms, frogs, fish, and insects such as cockroach, grasshopper, houseflies, mosquitoes and ants, etc. The respiration which takes place without oxygen is called anaerobic respiration. The microscopic organisms like yeast and some bacteria obtain energy by anaerobic respiration which is called! In anaerobic respiration, the micro-organisms like yeast break down glucose food into ethanol and carbon dioxide, and release energy. This energy is then used by the micro-organisms. Anaerobic respiration produces much less energy which gets stored in the ATP molecules. The breaking down of glucose food during anaerobic respiration carried out by yeast plants can be represented as follows: Please note that during anaerobic respiration shown above , 1 molecule of glucose food produces only 2 energy-rich ATP molecules. A few organisms such as yeast plants and certain bacteria called anaerobic bacteria can obtain energy from food in the absence of oxygen by the process of anaerobic respiration. Please note that all the organisms which obtain energy by anaerobic respiration can live without oxygen of air. From this discussion we conclude that all the cells do not use oxygen to produce energy. Energy can be produced in cells even without oxygen. Please note that the whole process of anaerobic respiration takes place in the cytoplasm of cells. We can carry out the fermentation of sugar by using the anaerobic respiration of yeast as follows: Take some sugar solution or fruit juice in a test-tube and add a little of yeast to it. Close the mouth of the test-tube with a cork and allow it to stand for some time. Now, open the cork and smell. A characteristic smell of ethanol ethyl alcohol is obtained from the test-tube. A gas is also evolved during this process. When this gas is passed through lime-water, the lime-water turns milky showing that it is carbon dioxide gas. This experiment tells us that the products of fermentation of sugar brought about by yeast are ethanol and carbon dioxide. We the human beings obtain energy by aerobic respiration. But anaerobic respiration can sometimes take place in our muscles or the muscles of other animals. For example, anaerobic respiration takes place in our muscles during vigorous physical exercise when oxygen gets used up faster in the muscle cells than can be supplied by the blood. When anaerobic respiration takes place in human muscles or animal muscles , then glucose food is converted into lactic acid with the release of a small amount of energy. The breaking down of glucose food during anaerobic respiration in muscles can be represented as follows: The painful contractions of muscles are called cramps. Let us discuss this in a little more detail. During heavy physical exercise or any other heavy physical activity , most of the energy in our muscles in produced by aerobic respiration. Anaerobic respiration in muscles provides only some extra energy which is needed under the conditions of heavy physical activity like running very fast or running for a long time see the people running a long distance. The anaerobic respiration by muscles brings about partial breakdown of glucose food to form lactic acid. This lactic acid accumulates in the muscles. The accumulation of lactic acid in the muscles causes muscle cramps. Thus, muscle cramps occur due to the accumulation of lactic acid in muscles when the muscles respire an aerobically without oxygen while doing hard physical exercise. We can get relief from cramps in muscles caused by heavy exercise by taking a hot water bath or a massage. Hot water bath or massage improves the circulation of blood in the muscles. Due to improved blood flows the supply of oxygen to the muscles increases. This oxygen breaks down lactic acid accumulated in muscles into carbon dioxide and water, and hence gives us relief from cramps. The anaerobic respiration does not take place only in the muscles of human beings, it also takes place in the muscles of other animals such as lion, tiger, cheetah, deer, and many other animals when they run very fast and require much more energy than normal. This means that even the animals like lion, tiger, cheetah and deer, etc. The similarity between aerobic respiration and anaerobic respiration is that in both the cases, energy is produced by the breakdown of food like glucose. The main differences between aerobic respiration and anaerobic respiration are given below. Differences between Aerobic and Anaerobic Respiration Aerobic respiration 1. Aerobic respiration takes place in the presence of oxygen. Complete breakdown of food occurs in aerobic respiration. The end products in aerobic respiration are carbon dioxide and water. Aerobic respiration produces a considerable amount of energy. Anaerobic respiration takes place in the absence of oxygen. Partial breakdown of food occurs in anaerobic respiration. The end products in anaerobic respiration may be ethanol and carbon dioxide as in yeast plants , or lactic acid as in animal muscles. Much less energy is produced in anaerobic respiration. Let us answer one question now. The breakdown of pyruvate to give carbon dioxide, water and energy takes place in:

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Diurnal change of the dissolved oxygen concentration in intensive fish pond Figure 2. Relationship between the oxygen production and illumination in fertilized fish pond The relationship between illumination and oxygen production can be seen in Figure 2. The intensity of light affects significantly the oxygen budget of pond water. If the intensity of solar radiation is high during a day without overcast, a quantity of dissolved oxygen is produced. This covers the oxygen demand of respiration during the night. In the cases when solar radiation is less intensive because of cloud cover, the oxygen production and thus the oxygen reserve for the night is less. During the night the respiration of organisms in the water does not decrease - or at least not in the same rate - and the oxygen reserve of the pond water can be exhausted. Thus the concentration of dissolved oxygen can decrease below the lethal level for fish. This situation can be extremely dangerous at the end of a growing season in August, when the length of the days is shorter Figure 3 , the quantity of daytime production is less, and at the same time the biomass is the highest. Studying the values of oxygen saturation at 2 p. Transparency of the water can be decreased by over-production of phytoplankton too. The over-produced mass of phytoplankton has a self-screening effect and it can be a significant factor in intensively manured and foddered ponds. In these ponds production is limited only to the upper water layer and the production here can not cover the oxygen demand of the lower water layer where respiration is dominant. If the light conditions are not favourable a very dangerous situation can develop short day, cloudy sky. After over-production of phytoplankton, production can be decreased not only because of the self-screening effect but by the disruption of nutrient equilibrium. In critical cases heavy losses of plankton can take place. The relationship between oxygen production and water temperature in an intensive carp production pond is shown on Figure 5. Although the oxygen production of pond water will be higher and higher due to the increase of temperature, a critical situation occurs in the case of high water temperatures because the rate of oxygen consumption exceeds the rate of production. On the basis of measurements carried out in large scale fish ponds of Hungary it was found that oxygen consumption of the water in a pond full of weeds was nearly completely the result of respiratory action of macro-vegetation. In another case in a manured but empty fishpond the mass of phytoplankton decreased nearly to zero due to over-production of zooplankton. In this case the zooplankton was the main consumer of oxygen. In the case of a stocked fish pond on the other hand, the mass of zooplankton decreased to such a minimum level due to the consumption by fish that even the chemical destruction of the remaining zooplankton did not make any demonstrable change in oxygen consumption of the pond water. Fish pond water is a complicated biological complex, thus its oxygen consumption is different from pond to pond under different conditions. While oxygen production is dependent mainly on light conditions, respiration is mainly determined by water temperature and dissolved oxygen content of the water. In an intensive channel catfish production pond a correlation has been found between oxygen consumption of pond water and water temperature as shown in Figure 6. Determination of primary production and of oxygen consumption of pond water has been carried out by the Fish Culture Research Institute. Based on a mathematical analysis of daily oxygen curves, it was found that the intensity of respiration in the fish ponds studied has shown a significant daily rhythm, with an afternoon maximum, and that it has been in direct proportion to oxygen concentration Figure 7. The oxygen concentration in the surface of a fish pond at and hours Figure 5. The oxygen production in intensive fish pond as a function of water temperature Figure 6. The oxygen consumption of the water of a fish pond as a function of water temperature Figure 7. Relationship between the oxygen concentration and respiration Source: The oxygen consumption of some fresh water fishes 1. Oxygen fixation taking place in the water mud interfacial area can also not be neglected. The dissolved oxygen content of the water layer directly in contact with the mud is much lower than that of the upper layers of water. According to some studies the 24 hour-long oxygen consumption of the pond bottom is grams per m2. Generally all those fish species which live in fast flowing and oxygen rich streams e. Salmonids need high quantities of oxygen, and only a small decrease of dissolved oxygen can cause losses. At the same time the species which became accustomed to slow motion of the water or stagnant water e. Some fish species are also known, mainly in the tropics, to utilize the oxygen of the atmosphere by cutaneous respiration, intestinal and swim-bladder respiration or by a respiratory organ similar to lungs. Standard oxygen consumption means the quantity of oxygen consumed by the fish without swimming and feeding quantity of oxygen necessary for subsistence. Standard oxygen consumption is not dependent on oxygen saturation of the water but it is significantly influenced by water temperature. Figure 8 shows standard oxygen consumption of some fish species as a function of water temperature on the basis of the data of several authors. In the practice of fish culture the active oxygen consumption the oxygen consumed by swimming and feeding fish can be used. Active oxygen consumption by fish has been analyzed very rarely till now because of the technical difficulties of measuring, and available data can not be compared because of inaccurate or imperfect description of the circumstances of measurement. Table 2, showing oxygen consumption of different fish species, gives the size of fish and an idea of the motion where they have been cited. From Table 3 it is obvious that oxygen consumption by fish can significantly change at a given water temperature depending on the activity of fish. Table 2 shows that in identical conditions oxygen consumption by smaller size fish is higher. Figure 9 shows changes of oxygen consumption by common carp, grass carp, silver and bighead carp against body weight. Active oxygen consumption by fish has a strict connection with oxygen saturation of the water. Figure 10 shows the correlation between oxygen saturation and oxygen consumption by fish, for seven fish species. Some scientists are of the opinion that fish are able to sense a decrease of dissolved oxygen content of the water before it causes troubles in their respiration and therefore they look for water of higher oxygen content. If this is not successful and the dissolved oxygen content of the water decreases further, the respiratory motion of the fish is increased as long as the oxygen supply to respiratory muscles permits. This reaches a limit when further acceleration is hindered by lack of oxygen. Fish are tolerant till this level. If the dissolved oxygen content of the water decreases further, the pulsation of the heart slows down and the fish dies after a time depending on the resistance characteristic of the species. Lethal oxygen concentration is the dissolved oxygen content that can not be tolerated by the given fish species for a given period of time. Table 2 The oxygen consumption of several fish species Source: