

## **Relations of Dissolved Oxygen, Relations of Carbondioxide**

### **Relations of Dissolved Oxygen**

Oxygen supply in air and in natural waters affords a striking contrast. Normally, air contains oxygen to the extent of approximately 21 per cent, which is an abundant supply for the respiration of air breathing organisms.

One liter of water will contain only about 9 cc of oxygen when saturated with this gas, whereas a liter of air will have 210 cc. In view of the active interplay of oxygen producing and oxygen consuming processes in inland water sets the stage for serious limits in aquatic respiration.

#### Excess of oxygen

Moderate supersaturations of dissolved oxygen occur in natural waters from time to time, usually owing to the photosynthetic activities of large masses of green plants in very calm water. Under special and still rare circumstances, large accumulations of excess oxygen appear in the upper part of the thermocline or in deeper strata of a lake.

#### Normal dissolved oxygen requirements

In the dynamics of natural waters, oxygen supplying and oxygen consuming processes are in constant action, the limits of an adequate supply of dissolved oxygen for organisms become an important matter.

The minimal oxygen requirement may be affected somewhat by other environmental features, e.g., temperature, CO<sub>2</sub> and certain conditions existing within the organism itself such as age or life history stage. In general "dissolved oxygen at levels of 3ppm or lower should be regarded as hazardous to lethal under average stream and lake conditions; and that 5ppm or more of dissolved oxygen should be present in waters, if conditions are to be favorable for freshwater fishes". This statement assumes, of course, that other vital requirements are maintained within their proper limits. It also applies primarily to warm water fishes. It has been claimed that cold water fishes require a higher dissolved oxygen content.

The respiration of aquatic organisms depends not only on the dissolved oxygen content but also in a significant measure upon the temperature of the surrounding water; that the oxygen consumption is almost doubled by a rise of 10°C; that the same amount of dissolved oxygen has about twice as great a supply value at 5 as at 15°C.

#### Source of oxygen supply

##### 1.Storage of oxygen

The hemoglobin of the blood may act as a storehouse for oxygen that such storage at times of abundant free oxygen may furnish the supply during oxygen deficiency.

##### 2.Internal chemical transformation

The idea of chemical transformations taking place within the animal, such as occur in the utilization of foodstuffs in which oxygen is released and made available for recombination.

##### 3.Catalysts facilitating oxygen absorption

Many profundal bottom animals have manganese in their tissues. This element may serve as a catalyst, facilitating oxygen absorption at low tensions.

##### 4.Atomic oxygen from decaying plant tissues

The decomposing plant tissues in the profundal mud, even under anaerobic conditions, gradually liberate small amounts of an oxidizing substance could be utilized by the animals living in such close relationship to the decaying plant debris.

#### Temporary anaerobiosis

Animals living in the muddy bottoms of shallow water or other similar conditions in which the oxygen exhaustion occurs quickly and for limited times, may be forced to meet these temporarily unusual conditions.

Certain representatives of Protozoa, nematodes, earthworms, leeches, and immature stages of

insects, mollusks, fishes, and others exhibit this ability.

During oxygen lack a certain amount of energy may be released by the splitting of carbohydrates into reduced substances, thus building up an "oxygen debt," this debt being repaid by the increased rate of oxygen consumption when the organism is returned to aerobic conditions.

#### Some effects of insufficient dissolved oxygen

##### 1. Attempts to migrate

In lakes, it is usually an upward migration into overlying, better oxygenated waters.

##### 2. Onset of diseases

A close relation between insufficient dissolved oxygen to diseases of fishes, parasitic and bacterial and serious epidemics in the fish *Leucichthys artedi*, which seems to occupy the cooler water below the thermocline during summer.

##### 3. Suffocation beneath ice cover

Shallow waters with bottoms containing large amounts of putrescible matter and occurring in regions where prolonged ice cover in winter is common may, at times, almost or completely exhaust the dissolved oxygen of the unfrozen water with resulting mortality (winter kill) among the organisms.

##### 4. Summer kill

Critically low dissolved oxygen and unfavorable temperatures have been suspected as causal agents, but the case is not clear since other conditions were probably in a simultaneous state of flux. Warm waters reduced solubility of DO and release of oxygen by warm waters (less holding capacity).

#### **Relations of Carbon Dioxide**

##### General effects on organisms

Carbon dioxide is one of the most important substances in the life of organisms.

##### Small quantities

Usually, the quantities in the air are very small but yet sufficient for the photosynthetic activities of chlorophyll-bearing plants. Likewise, in natural waters, the amounts may be very small in the upper circulating waters.

##### Large quantities

Large quantities of carbon dioxide usually have a detrimental effect. Ordinarily, accumulations in unpolluted, natural waters do not reach such lethal amounts, owing to the ease with which they are released into the air or combine chemically. Increasing amounts of free carbon dioxide in association with other decomposition products may gradually render the hypolimnion untenable by all organisms save the resistant anaerobic animals in the bottom.

Such accumulations may render bottom waters acid in reaction and thus affect organisms sensitive to acid waters. High carbon dioxide content seems to be more toxic in the presence of low oxygen content.

Since an excess of dissolved carbon dioxide is usually accompanied by a much reduced dissolved oxygen content and other important conditions, it has been proposed that the carbon dioxide content of the water is probably the best single index of the suitability of water for fishes.

Carbon dioxide has a very definite effect upon the affinity of blood for oxygen in fishes and certain other animals.

Fishes may tolerate wide, but not sudden, ranges of carbon dioxide tension of the water by "increasing the alkali reserve of their blood in high carbon dioxide tension water and by lowering the alkali reserve of their blood in low carbon dioxide water".

##### Carbon dioxide tension

While the carbon dioxide tension within natural waters and within the atmosphere constantly tends toward equilibrium, circumstances prevailing in the water (slow diffusion, rapid production of carbon dioxide, insufficient agitation of the water) may be such that at some depths the carbon dioxide tension is greater than in the air.

## **Relations of other Dissolved Gases : Methane, Hydrogen Sulfide**

### Methane

Some have claimed that it is nontoxic; others, that its effects on organisms are minor or that, at most, it may be occasionally toxic to animals or that it may cause them to migrate from particular situations. Possibly methane accumulations in bottom waters may have something to do with the increasingly severe conditions which develop with the progress of stagnation periods.

### Hydrogen sulfide

Inherently, hydrogen sulfide is very poisonous. Certain marine fishes are said to be very sensitive to this gas and to avoid water containing it.

## **Nitrogen, Ammonia, Dissolved solids, Other elements, Dissolved organic matter**

### **Nitrogen**

Free nitrogen has usually been supposed to be the least important of the dissolved gases when it occurs in normal quantities. Excess nitrogen is said to cause gas disease in fishes. Unusual amounts may produce entry of the gas into the circulatory systems of aquatic animals, causing stoppage.

### **Ammonia**

Scanty information is available on the biological relations of gaseous ammonia as produced in natural waters.

### **Dissolved solids**

#### Relations of inorganic nitrogen compounds

Ammonium salts, nitrites, and nitrates furnish a supply of nitrogen which is essential in the fundamental food relations of organisms. Ammonium salts ("ammonia nitrogen" or "free ammonia") constitute the first stage in mineralization of organic nitrogen. It is usually considered that nitrates supply nitrogen in more available form, although the other two compounds, particularly ammonium salts, are utilized to some extent.

While some plants seem to prefer nitrates, there are others which grow equally well with both nitrites and ammonium salts. Variations in the quantities present in water are correlated with the growth seasons of plants and with the temperatures which control, to some extent, the rate of bacterial action. Ordinarily, nitrogen in its final oxidized form as nitrate does not occur in great amounts in natural, uncontaminated waters. The Algae, water weeds, and nitrate reducing bacteria are the important consumers of nitrogen content and that the nitrifying bacteria aid in increasing the nitrate content. Nitrogen is considered to be one of the most important limiting factors in the development of phytoplankton. It is one of the nutritive substances necessary for the production of chlorophyll. Formation of chlorophyll ceases very quickly with nitrate deficiency. Ammonium salts in excess are reported as poisonous to fishes if present with carbonates.

#### Relations of silicon

Since diatoms require silicon for the manufacture of their shells, and since they constitute a very prominent and strategic group in the plankton at large, the available supply of silicon in the water is regarded as a matter of importance. The production of diatoms is directly determined by the silicon supply. Silica deposition by diatoms is a one way process; that silica in the form of diatom shells is highly resistant to passage into solution in water; that diatom shells once formed are practically permanent in many waters. Silicon removed from sea water by diatoms and other organisms may return to solution after they die, or it may sink to the bottom.

Development and success of the fresh water sponges depend upon an adequate supply of silicon for the manufacture of spicules. Some permanent loss of silicon is expected, in average situations, owing to transportation by currents, to outlets, and to burial in bottom deposits. In the presence of such losses, a source of renewal is necessary if a body of water is to avoid silicon decline to a critical level.

#### Relations of phosphorus

Since the amount of soluble phosphorus in natural, unmodified waters is small and since phytoplankton requires an adequate supply of phosphorus, it is now generally regarded as a limiting factor. Phytoplankton occupies the upper waters because of their light requirements die and sinks to the bottom, carrying away a certain amount of the phosphorus. Restoration of phosphorus to the upper waters might be brought about by inflow of waters rich in phosphate or by the return to circulation of the phosphorus containing materials, return of which would be facilitated by overturns or other forms of circulation.

#### The nitrogen phosphorus ratio

The relation of these two substances is better known for sea water than for fresh water. The concentrations of the two substances closely parallel each other. In sea water it appears that the ratio tends to approach a constant value, with nitrogen exceeding considerably the phosphorus content, and that as claimed these substances occur in marine plankton in about the same proportions. Further, the ratio in inland waters may be different not only in numerical value but also in the range of deviation from proposed mean. This matter is still in the pioneering stage, but is suggestive of basic limnological possibilities and deserves more investigation.

#### **Other elements**

The significance of several other elements appears most prominently in their essential roles in the metabolism of the various groups of aquatic plants. Calcium is required by all green plants except some of the lower Algae; is not necessary for the fungi; and while necessary for the non-chlorophyll flowering plants, they usually contain less calcium than do chlorophyll bearing ones. It appears to have several physiological roles, such as (1) relation to the proper translocation of the carbohydrates; (2) an integral component of plant tissue; (3) facilitation the availability of other ions; and (4) an antidoting agent reducing the toxic effects of single salt solutions of sodium, potassium and magnesium.

Magnesium is a component of chlorophyll and must be present for its proper development. It appears to act as a carrier of phosphorus, at least in some instances. Quantities of magnesium larger than usual in natural waters may be toxic to some aquatic organisms. Cladocerans are wholly absent from certain lakes (Lake Tanganyika, Lake Kivu) may be owing to the excess of magnesium over calcium salts.

Iron must be supplied for plant growth and development. It functions in the proper production of chlorophyll, although it does not enter into the chemical composition of chlorophyll. It acts as a catalyzer; others, that iron is the oxygen carrying substance in certain respiratory processes. Both the quantity and the form in which it is presented to the plant are now known to be important, these being conditioned by the features of the environment (hydrogen ion concentration, organic matters, and others) and the kind of plant involved. Most algae grow best when the water has a ferric oxide content of 0.2 to 2 mg/litre, but distinct toxicity occurs when the available iron exceeds 5mg. however, many natural waters may contain more than 5mg. of iron without being toxic owing to the buffer action of organic compounds or of calcium salts. Toxic oxidation products of pyrites are said to be formed in peat deposits. Two other relations of high iron content have received attention in limnological literature: (1) reduction of nitrates to nitrites by ferrous salts in the presence of oxygen and (2) reduction of dissolved oxygen in the presence of iron.

Sodium, while apparently not absolutely necessary for plant growth and development, is evidently a very desirable element. It may serve one or more of the following roles: (1) act as a conserver of potassium, since less is absorbed when sodium is present; (2) replace potassium to a limited extent as a plant nutritive element; (3) render soil-absorbed potassium more available to plants; and (4) be an antidoting agent against certain toxic salts in the medium.

Potassium is a fixed requirement for plants. Its function is imperfectly known, but it appears to be two fold; (1) a fundamental requirement in food manufacture and (2) a catalyst. Sulfur must be

provided for plant growth and development. It forms a necessary material in the composition of protein and other constituents of the plant.

### **Trace elements**

By trace elements is meant those chemical elements essential to the well being of animals and plants but required only in extremely small quantities. Prominent among these trace elements are copper, manganese, zinc, boron, lead, cobalt and iodine.

### **Dissolved organic matter**

Many of the minute, more or less undifferentiated organisms, such as the bacteria, certain Algae, and certain protozoa, must depend upon the dissolved materials in their environments for the substances necessary to growth and development. At one time, the discovery that many microorganisms use particulate foods cast some doubt on the direct utilization of dissolved substances by many organisms. However, it has since been clearly demonstrated that bacteria, diatoms, most if not all other phytoplankton, and some of the Protozoa normally utilize and depend upon both the dissolved inorganic and the dissolved organic materials in their surroundings. It likewise seems probable that many other small organisms which lack a digestive tract or other provisions for introducing particulate foods will be discovered to depend upon these materials, wholly or in part.

The plankton in the ocean is entirely insufficient in amount to supply the necessary nourishment for those animals supposed to depend upon it and (2) that an abundant supply of food is available in the dissolved organic matter in the water. From computations of the minimal carbon requirements of certain marine animals for a given time unit and determinations of the plankton content of the surrounding water, he insisted that the amount of water strained by the animal to secure the minimal amount of carbon was impossibly large. In this way, he showed that a certain common marine sponge would need to filter 2421 of sea water per hour (about four thousand times its own bulk) to secure the minimal amount of carbon from the plankton.

The chlorophyll bearing phytoplankton is not dependent upon nitrogen salts or upon carbon dioxide in water for either nitrogen or carbon but, instead can utilize atmospheric nitrogen dissolved in the water (nitrogen fixation); that the nitrites, nitrates, and ammonium salts in the water may remain unconsumed and that bicarbonates of calcium and magnesium can be broken up, the half bound carbon dioxide furnishing a carbon supply for the green phytoplankton. This reaction, they claimed, is of such magnitude that at the spring plankton maximum, assuming that it occurs to the same extent down to a depth of 100m., the carbon so provided would be sufficient for a phytoplankton crop of 10 tons or more per acre, wet weight.

1.Organic detritus and living organisms in water usually provide food in necessary quantity for the aquatic animals present. Certain protozoa and possibly sponges may absorb dissolved organic matter from the water.

2.The rather large quantities (10 mg. per l. or more) of dissolved organic matter in fresh water include proteins in colloidal solution and several amino acids greatly diluted. Carbohydrates present do not appear to be in readily assimilable form.

3.Dissolved organic matter seems to be principally waste products, some of which are very resistant to bacterial action.

4.Very little of the organic matter produced by living Algae is given off to the water; 90 to 95 per cent of it is stored in the organisms.

5.It is possible that higher animals absorb insignificant quantities of the dissolved substances.

6.Experimental evidence is now available which indicates that tadpoles, mussels and probably other animals may take up dissolved organic matter from rather concentrated solutions and are thus enabled to thrive and grow, at least for a considerable period of time, in the absence of particulate food.

7.Experiments of certain investigators show that absorption of dissolved organic matter by tadpoles,

mussels and starfish occurs through the intestine and not through gills or integument. The integument and gills of aquatic animals seem to be, for the most part, impermeable to organic substances.

In general, marine invertebrates are permeable to water, salts, and organic solutes but that teleosts and fresh water invertebrates are very slight permeability. In *Daphnia magna* organic substances in true solution were not used for food, but organic matter in colloidal form was utilized. The fishes may absorb a slight amount of dissolved substance, but the securing of a large proportion of their nutriment in this way, as has been postulated, appears very doubtful.