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VENTILATION RATES FOR CARASSIUS AURATUS 
DURING CHANGES IN DISSOLVED OXYGEN

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ABSTRACT--This experiment was designed to determine whether dissolved oxygen concentrations would influence the ventilation rate of goldfish, *Carassius auratus*. Ventilation rate can be determined by counting opercular movements. Opercular movements of the same five goldfish were counted at three different levels of dissolved oxygen to determine whether there were differences in ventilation rates. Average ventilation rates were established for each of the three levels of dissolved oxygen and compared statistically. There were significant differences in the ventilation rates averages at each of the three levels. *Carassius auratus* will exhibit changes in ventilation rates when dissolved oxygen levels change.

INTRODUCTION--A crucial part of maintaining a healthy environment for fish in an aquarium is maintaining the proper amount of dissolved oxygen in the water. This is important because fish absorb oxygen essential to their physiological needs from the water (Spotte, 1979). Oxygen in the water is used during cell respiration and metabolism. Therefore, too much or too little oxygen can have a profound effect on specific biological processes (Hoar, Randall & Brett, 1970). Without the proper amount of dissolved oxygen a fish may die or at the very least become debilitated.

Improper oxygen levels reduce health or cause death because oxygen is extremely important in the processes of cellular metabolism and respiration. During respiration tissue cells are replenished with oxygen while removing carbon dioxide produced during the metabolic process (Hoar, Randall & Brett, 1970). When adequate amounts of oxygen
are not available to tissues, the rate of aerobic metabolism is limited directly (Pauly, 1981). When metabolism is limited it affects the animal in many ways. For instance, a decrease in metabolism affects fish by limiting growth, by providing less energy for activity, by decreasing the potential for reproduction, and decreasing the ability of the immune system to fight disease (Hoar, Randall & Brett, 1970).

Even more important than the adverse affects of slowing down metabolism is the potential for death caused by decrease in the efficiency of cellular respiration at low oxygen levels. Cellular respiration is important because it removes waste, primarily carbon dioxide, produced during metabolism. If the tissue is not replenished with oxygen a toxic level of carbon dioxide will build up.

Respiration occurs when oxygen is transported to tissue cells by hemoglobin, a pigment in the blood. When oxygenated water is passed over the gill lamellae of the fish, a process known as ventilation, the oxygen diffuses across the membrane of the lamellae into the blood. Oxygen in the blood bonds with hemoglobin. The oxygenated hemoglobin travels throughout the fish replenishing cells with oxygen and removing carbon dioxide waste. The carbon dioxide waste is transported back to the lamellae where it is released to the external environment, ridding the fish of poisonous carbon dioxide. However, if there is an inadequate amount of oxygen in the water then hemoglobin cannot properly replenish the tissue cells. This results in an incomplete respiration process causing a buildup of carbon dioxide within the fish. Due to the toxicity of carbon dioxide, a buildup will cause a loss of equilibrium, coma, and ultimately death by asphyxiation (Andrews, Exell & Carrington, 1988).
Death can also occur as a result of too much oxygen dissolved in water. Although most problems associated with oxygen levels in aquariums concern low oxygen, there is the potential to harm fish by supersaturating the aquarium. At critically high levels of dissolved oxygen an excess of oxygen can accumulate in the blood of fish. This excess can lead to bubbles in the bloodstream. If the bubbles accumulate a blockage or embolism can occur resulting in the death of the animal (Andrews, Exell & Carrington, 1988).

These potential effects that an inappropriate level of dissolved oxygen may have on fish illustrates the importance of maintaining dissolved oxygen at a healthy level. Maintaining a healthy level of dissolved oxygen is not always easy. First you must know what the correct level of oxygen is for the particular species of fish in the aquarium. Certain fish have adapted to different levels of dissolved oxygen. It is important to know the level of oxygen that is relevant to each species. There are many environmental factors that play a role in the amount of dissolved oxygen to which a particular fish is accustomed. These factors include the waters ambient temperature levels, ambient atmospheric pressure, salinity level, biochemical oxygen demand, daily photoperiod, and flow rate just to name a few (Moe, 1989; Andrews, Exell & Carrington, 1988).

Other factors an aquarist should know concern the behavioral aspects of the animal. For instance, is the animal benthic or pelagic? Is it lethargic by nature or very active? Does it live in dark environments, such as a cave, or does it live in sunlight amongst the aquatic flora? All of these aspects may require different ambient levels of dissolved oxygen (Burgess, 1995). Therefore it is very important to know which aspects apply to each species.
Understanding which environmental factors are present in the natural habitat of a species is important because these factors dictate the amount of dissolved oxygen present in the water. A knowledge of the dynamics of an aquatic environment is very important in replicating the natural environment. The most important factors that affect dissolved oxygen are temperature, salinity, atmospheric pressure, biochemical oxygen demand (BOD), and the laminar layer (Moe, 1989; Andrews, Exell & Carrington, 1988).

Temperature has the strongest affect on the amount of dissolved oxygen in an aquarium. Temperature affects the solubility of oxygen in water, the higher the temperature of the water the lower the solubility of oxygen in that water (see fig. 1). This is important because temperature has the ability to change rapidly (Spotte, 1979). This rapid change not only affects the amount of oxygen dissolved in the water, but it changes the body temperature of any ectothermic animal living in the aquarium. An increase in body temperature of fish results in an increase in metabolism (Fry & Hart, 1948). Metabolism is a direct measurement of oxygen consumption (Beamish, 1964a). Therefore, an increase in metabolism increases oxygen demand. Studies supporting this have shown that an increase in temperature of 10° C causes ectothermic animals to approximately double their oxygen uptake (Kanungo & Prosser, 1959). In addition Brett showed that at 5° C standard metabolic rate for sockeye salmon was 41 mg O₂/Kg of fish/hour and at 24° C standard metabolic rate for
sockeye salmon was 196 mg of O₂/ Kg of fish/hour (Brett, 1964). The overall result is that an increase in temperature will reduce the amount of dissolved oxygen present in the aquarium while increasing the demands for oxygen in the animal. Ultimately the oxygen demands of the fish cannot be met and the fish may die of asphyxiation (Andrews, Exell & Carrington, 1988).

Temperature is not the only regulating factor for dissolved oxygen. Salinity is another factor that will affect the amount of dissolved oxygen in water (Spotte, 1979). As with temperature, the solubility of oxygen in water is decreased with the increase of salinity (see fig. 2). However, salinity does not have as profound an affect on oxygen solubility in water as temperature because it does not change as rapidly (Moe, 1989). Establishing the proper salt levels initially for the fish will usually control the effect salinity will have on the amount of dissolved oxygen in the aquarium.

Another factor that can affect the amount of dissolved oxygen is atmospheric pressure. At lower altitudes oxygen is more compressed. Molecules of oxygen are packed together more closely allowing for more oxygen to be introduced at the air/water interface of the aquarium (Spotte, 1979). Therefore, there will be less dissolved oxygen in an aquarium at higher altitudes (Spotte, 1979). This atmospheric pressure does not
change enough to have a significant effect on existing aquariums and need only be considered when establishing the aquarium.

BOD or biochemical oxygen demand is another important factor. The BOD rate measures the competition for oxygen within the aquarium. More precisely, BOD measures the rate at which oxygen is used to oxidize any inorganic or organic material within the aquarium (Andrews, Exell & Carrington, 1988). Larger fish require more oxygen than smaller fish even though the rate of oxygen consumption per unit of mass decreases as fish get bigger (Wooton, 1992). Large fish combined with other oxygen demanding elements within an aquarium can quickly exhaust the supply of dissolved oxygen within a small aquarium. Therefore, the BOD rate is an important consideration in maintaining dissolved oxygen levels (Spotte, 1979).

The final factor discussed is the laminar layer. The laminar layer is the layer that covers the surface where air and water meet (Moe, 1989). The laminar layer is thicker if it is still. Less air will be exchanged at this interface if there is a thick layer. Moving this layer by introducing water into the aquarium or by blowing air across the surface disrupts the surface tension. This disruption enables the oxygen to dissolve more easily into solution, allowing for more dissolved oxygen in the water (Spotte, 1979).

Careful aquarists monitor and control these variables constantly. Maintaining these variables provides a healthy environment for the fish. However, a more direct and objective index illustrating the level of dissolved oxygen would be useful. Knowing the normal ventilation rate of fish under healthy conditions, and knowing that a change will
occur in the ventilation rates with a change in dissolved oxygen could provide such an index.

This study shows that *Carassius auratus* has a consistent ventilation rate when kept at a level of dissolved oxygen known to be healthy. In addition, it shows that the ventilation rate will change when the level of dissolved oxygen changes. This implies that the aquarist can use the ventilation rate as a diagnostic tool for monitoring the level of dissolved oxygen.

**MATERIALS AND METHODS**—Two 38 liter aquariums were established. Each aquarium contained fresh water, a carbon filled flow through filter, an aquarium heater that maintained a temperature of 78°F, and an undergravel filter with a half inch of gravel substrate. The first aquarium was the control aquarium in which oxygen saturation was maintained at approximately 6.3 mg./liter at 78°F and 2100 feet above sea level. Five *Carassius auratus* were placed in the control aquarium for one week. Ventilation rates were recorded for a twenty second period for all five fish three times a day for a week. The ventilation rates were recorded at 9:00 a.m. approximately one hour after the morning feeding, in the afternoon at 1:30 p.m., and in the afternoon at 5:00 p.m., one hour after the night feeding. This schedule provided fifteen counts of ventilation rate per fish per day for one week. This resulted in 105 counts for the five fish for each dissolved oxygen level (see Table 1).

The same five fish were placed in the second aquarium for a period of two weeks. The second aquarium was set up the same as the first except for a layer of Parafilm, a non-
permeable plastic sheet, placed on the surface of the water. The Parafilm reduced the diffusion rate of oxygen across the water surface. The entire surface of the water was covered with Parafilm which allowed for the dissolved oxygen to be maintained at an average of 3.02 mg. /liter at 78° F, 2100 feet above sea level, for one week. Ventilation rates were counted using the same schedule established for the control aquarium (see Table 1).

The Parafilm was removed from one third of the surface of the same aquarium, enabling maintenance of the third and final level of dissolved oxygen used during the study. The third level was approximately 4.91 mg. /liter at 78° F, 2100 feet above sea level. The same five fish were exposed to this level for one week during which ventilation rates were counted using the same schedule established for the control aquarium (see Table 1).

A fourth level of dissolved oxygen was attempted. This level would have consisted of a dissolved oxygen level above the level of saturation. This could not be accomplished however because the supersaturation of the aquarium could not be maintained long enough to collect data.

RESULTS--The control aquarium yielded a mean ventilation rate of 101.7 opercular movements per minute at an average 6.36 mg. of O₂ / liter of H₂O. There were a total of 3560 opercular movements counted in 105 periods during the seven day period (see Table 1).
The second concentration of dissolved oxygen was established at an average of 3.01 mg. of $O_2$ / liter $H_2O$. This level of dissolved oxygen yielded a mean ventilation rate of 124.2 opercular movements per minute, with a total of 4355 opercular movements counted during the seven day period (see Table 1).

The third and final concentration of dissolved oxygen was established at an average of 4.91 mg. of oxygen per liter of water. The mean ventilation rate was 78.3 opercular movements with a total of 2745 opercular movements for the seven day period (see Table 1).

The mean opercular movements at all three dissolved oxygen concentrations were compared statistically (see Table 2). These calculations show that there is a significant difference between the mean ventilation rates at three oxygen concentrations. The mean ventilation rate at low and mid levels of dissolved oxygen differ significantly from rates exhibited by fish in the control aquarium (Table 2).

DISCUSSION—The results of the research illustrate that there is a measurable change in the ventilation rate of *Carassius auratus* when the level of dissolved oxygen changes from 6.36 mg $O_2$ /liter $H_2O$ to 4.91 mg $O_2$ /liter $H_2O$ and ultimately to 3.01 mg $O_2$ /liter $H_2O$ while maintaining other parameters constant.

An average ventilation rate of 102 opercular movements per fish per minute were counted within the control aquarium. The mean has a standard deviation of 5.8, a standard error of .56 and a critical value of $\pm 1.11$ at .05%. The 95% confidence interval around the mean is therefore 100.59—102.81.
These numbers were generated from an aquarium containing five healthy *Carassius auratus* maintained under conditions determined to be optimal for husbandry (Burgess, 1995). The averages were assumed to represent normal *Carassius auratus* ventilation rates and were used to determine the significance of the difference in ventilation rate averages for the other two aquariums. As a result, when compared to the control concentrations of dissolved oxygen in the other two aquaria are associated with significant differences in ventilation rates.

The second concentration of dissolved oxygen was established at 3.02 mg. of O₂ / liter H₂O. At this level of dissolved oxygen an average of 124.2 opercular movements per fish per minute were counted. Surprisingly, there was an increase of 22.5 opercular movements per fish per minute when the dissolved oxygen level was decreased 3.35 mg. of O₂ /liter H₂O. This average places the number of opercular movements outside of the confidence interval of the control average showing that there was a statistically significant difference in the observable rate of ventilation of the gills.

This increase in opercular movements was not anticipated. Studies show that goldfish activity decreases at lower ambient oxygen levels, suggesting that an organism adjusts to a limiting factor, such as a low dissolved oxygen level, and restricts activity during the period when it is imposed unless that factor is at a lethal level (Knutty, 1968b). In addition to a significant increase in the opercular movement of the five goldfish there was an increase in activity. Erratic patterns of swimming were exhibited along with what appeared to be labored non-rhythmical breathing, implying that the dissolved oxygen may have been close to the lethal level, preventing the fish from adjusting.
The third concentration of dissolved oxygen was established at 4.91 mg O$_2$/liter H$_2$O. This level was chosen to be between the control level and the third level to discover if the effect of an increased ventilation rate was consistent with a decrease in dissolved oxygen. The results, an average of 78.3 opercular movements per fish per minute, illustrated that there was no consistently inverse relationship between ventilation rate and oxygen depletion. However, the average ventilation rate at this level did prove to be significantly different statistically. There was a decrease in ventilation rate of 23.4 opercular movements per fish per minute. This placed the average outside of the confidence interval for the control showing a significant change in the amount of opercular movements per fish per minute for \textit{Carassius auratus} in an aquarium with 4.91 mg. of O$_2$/liter of H$_2$O. The change in the average ventilation rate for this concentration of dissolved oxygen was more indicative of the expected results of a decrease in oxygen in solution.

Unlike the lowest level of dissolved oxygen, the fish swam lethargically in controlled patterns close to the surface of the water. The five fish seemed to spread out as far as possible while staying near the surface where the water was not covered by the parafilm. They seemed to be utilizing the oxygen that was dissolving into the water, uninhibited by the parafilm. This is known as aquatic surface respiration, and is shown to occur when the dissolved oxygen level decreases, causing the fish to come close to the well oxygenated surface (Kramer, 1983). This probably did not occur with the fish in the lowest concentration of dissolved oxygen because the surface was completely covered with the parafilm, preventing the fish from exploiting oxygen near the surface. Unlike the fish in the low concentration, the fish in the mid level of dissolved oxygen exhibited signs of
adjustment to the limiting factor of low dissolved oxygen levels described by Knutty (1969).

The results of the study show that ventilation rate changes with changes in the level of dissolved oxygen in an aquarium. The ventilation rate will decrease with a moderate change in dissolved oxygen, and will increase dramatically as the level of dissolved oxygen approaches a lethal concentration. However, there are some problems that must be addressed. The aquarist must know the average ventilation rate for the particular species under optimal dissolved oxygen levels, what other external factors are present that will affect the ventilation rate, and whether biomass affects the average ventilation rate. The fish must also be large enough to observe and count opercular movements accurately. These are just a few problems that come to mind.

These problems do not disprove the hypothesis. The hypothesis, that *Carassius auratus* will exhibit noticeable changes in ventilation rate with a change in dissolved oxygen, was supported. However, there are many factors that affect ventilation rate. Without a good understanding of those factors, ventilation rate is not a simple, useful or reliable index for monitoring dissolved oxygen levels in an aquarium. The ventilation rate, in concert with other diagnostic indexes, such as behavior or color changes, does reveal a lot of useful information about the conditions in an aquarium to the knowledgeable aquarist. However, due to the complexity of an aquarium ecosystem and its inhabitants, ventilation rates cannot be solely used to reliably determine dissolved oxygen levels.
### Table 1: Oxygen Concentrations and Ventilation rates of Goldfish

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>mid level</th>
<th>low level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MEAN O2 CONC.</strong></td>
<td>6.36 mg O2/L-H2O</td>
<td>4.91 mg O2/L-H2O</td>
<td>3.01 mg O2/L-H2O</td>
</tr>
<tr>
<td><strong>MEAN VENT. RATE</strong></td>
<td>101.7</td>
<td>78.3</td>
<td>124.2</td>
</tr>
<tr>
<td><strong>MAX. V. RATE</strong></td>
<td>159</td>
<td>162</td>
<td>108</td>
</tr>
<tr>
<td><strong>MIN. V. RATE</strong></td>
<td>63</td>
<td>57</td>
<td>78</td>
</tr>
<tr>
<td><strong>TOTAL V. RATE</strong></td>
<td>3560</td>
<td>2745</td>
<td>4355</td>
</tr>
<tr>
<td><strong>TOTAL COUNTS</strong></td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
</tbody>
</table>

### Table 2: Statistical Analysis of Ventilation Rates of Goldfish

Under 3 Different conditions of Oxygen Concentration.

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>mid level</th>
<th>low level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SUM OF DATA</strong></td>
<td>3560</td>
<td>2745</td>
<td>4355</td>
</tr>
<tr>
<td><strong>SUM OF DATA SQUARED</strong></td>
<td>124202</td>
<td>71122</td>
<td>169597</td>
</tr>
<tr>
<td><strong>MEAN DATA</strong></td>
<td>101.7</td>
<td>78.3</td>
<td>124.2</td>
</tr>
<tr>
<td><strong>STANDARD DEVIATION</strong></td>
<td>5.8</td>
<td>2.5</td>
<td>10.3</td>
</tr>
<tr>
<td><strong>STANDARD ERROR</strong></td>
<td>0.56</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td><strong>CRITICAL VALUE</strong></td>
<td>1.11</td>
<td>0.4</td>
<td>1.98</td>
</tr>
<tr>
<td><strong>CONFIDENCE INTERVAL</strong></td>
<td>100.59&lt;101.7&lt;102.81</td>
<td>77.9&lt;78.3&lt;78.7</td>
<td>122.2&lt;124.2&lt;126.2</td>
</tr>
</tbody>
</table>
Literature Cited


