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OXYGEN CONSUMPTION IN THE FATHEAD MINNOW (*PIMEPHALES PROMELAS* RAFINESQUE)—II EFFECTS OF pH, OSMOTIC PRESSURE, AND LIGHT LEVEL*

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Abstract—1. There is a curvilinear relationship between oxygen consumption (OC in $cm^3/g^{1.053}$ per hr) and pH, yielding the equation: $OC = -0.0612(pH)^2 + 1.0478(pH) - 4.051$.

2. The relationship between OC and osmotic pressure (OP in mOsm/kg) for natural water is shown by the equation: $OC = 0.0091(OP)^2 - 0.0436(OP) + 0.208$, and that for NaCl treated water by: $OC = 0.0009(OP)^3 - 0.0208(OP)^2 + 0.104(OP) + 0.190$.

3. A significant relationship was exhibited between oxygen consumption and light intensity (LI in W/m^2), producing the line given by: $OC = 0.0026(LI) + 0.336$.

INTRODUCTION

This is a continuation of an earlier work (Wares & Igram, 1978) dealing with the effect of various environmental parameters on the metabolism (oxygen consumption) of the fathead minnow (*Pimephales promelas* Rafinesque). This study considers further natural environmental conditions, as well as some rather abnormal factors brought about by man's interaction with the ecosystem.

MATERIALS AND METHODS

Minnows (*Pimephales promelas* Rafinesque) used in this study were obtained commercially from the stock of a local bait shop, during March and April, 1977. They were maintained in aerated 30 gallon aquaria at room temperature (21 ± 1°C), and were fed commercial fish food at regular intervals. After acclimation to these laboratory conditions for at least one week prior to testing, minnows were exposed to a cycle of 12 hr light and 12 hr dark (centered on 7:00 a.m.) at an average light intensity of 1.5 W/m^2, measured at the experiment vessel surface using equipment and procedures described earlier (Wares & Igram, 1978). All testing was conducted between the hours of 1:00 p.m. and 5:00 p.m. in order to avoid variation due to diurnal fluctuations. Essentially all of the water was obtained along with the fish from the bait shop, and used in the studies.

Oxygen consumption was determined as described previously (Wares & Igram, 1978). The paragraphs following serve to explain in further detail the conditions of each specific test.

pH

pH adjustments were accomplished by adding concentrated HCl or NaOH pellets to tank water.

Osmotic pressure

Osmotic pressure ranges were prepared between 12–10, 9–8, 6, 4, 2 and 0 mOsm. Natural water was concentrated by boiling or diluted with distilled water. Similar ranges were obtained by adding NaCl to distilled water.

Light level

Fish of relatively uniform size (av. wt 1.70 g) were used to obviate effects of size. A light gradient was established in a small, windowless room using incandescent lamps. Average light intensities of 0, 5, 7, 10, 25, 30 and 50 W/m^2 were used. Four fish and an empty control vessel were run at each level except at 50 W/m^2, where three fish were tested.

RESULTS

In all facets of experimentation, oxygen consumption was weight adjusted (Wares & Igram, 1978). The figures in parentheses below the coefficients of the equations are standard errors.

pH

A curvilinear relationship was found to exist between oxygen consumption (OC) and pH. The equation being:

$$OC = -0.0612(pH)^2 + 1.0478(pH) - 4.051,$$
$$(\pm 0.0145) \quad (\pm 0.2471) \quad (\pm 1.034)$$

where OC is oxygen consumption ($cm^3/g^{1.053}$ per hr) and pH is in standard pH units ($F = 8.999$, d.f. 2 and 41, $P = 0.006$, and $r^2 = 0.3051$). Figure 1 illustrates this relationship. A maximum metabolic rate is seen at a pH of 8.57 (Studier *et al.*, 1975), with nearly no oxygen consumption at pHs near 5.9 and 11.2. It should be noted that minnows at a pH of 10.9 were seen to experience some denaturation of their mucous coat as evidenced by visible mucus streaming from their bodies.

Osmotic pressure

Natural water yielded the equation:

$$OC = 0.006(OP)^2 - 0.013(OP) + 0.191,$$
$$(\pm 0.005) \quad (\pm 0.028) \quad (\pm 0.042)$$

where OP is osmotic pressure in mOsm/kg ($F = 11.248$, d.f. 2 and 27, $P < 0.001$, and $r^2 = 0.454$). Figure 2 illustrates this.

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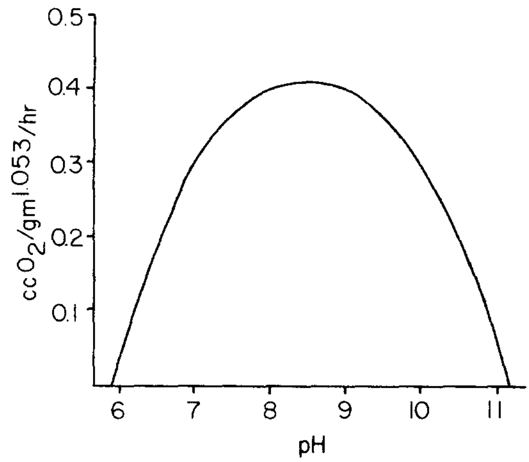

Fig. 1. Oxygen consumption of individual *Pimephales promelas* at varying pHs.

Sodium chloride supplemented water gave the equation:

$$OC = 0.00099(OP)^3 - 0.208(OP)^2 + 0.104(OP) + 0.190$$
$$(\pm 0.0002) \quad (\pm 0.005) \quad (\pm 0.023) \quad (\pm 0.031)$$

($F = 12.24$, d.f. 3 and 28, $P < 0.001$, and $r^2 = 0.567$). Figure 3 illustrates this.

Light level

Regression analysis of oxygen consumption as a function of light intensity rendered a linear relationship represented by the equation:

$$OC = 0.00263(LI) + 0.336,$$
$$(\pm 0.025) \quad (\pm 0.083)$$

where LI is light intensity in W/m^2 ($F = 6.2$, d.f. 1 and 25, $P < 0.025$, and $r^2 = 0.199$). A value of 1.5 W/m^2 was used due to the dictates of experimental conditions and was not significantly different from oxygen consumption at 0 W/m^2 (in the dark).

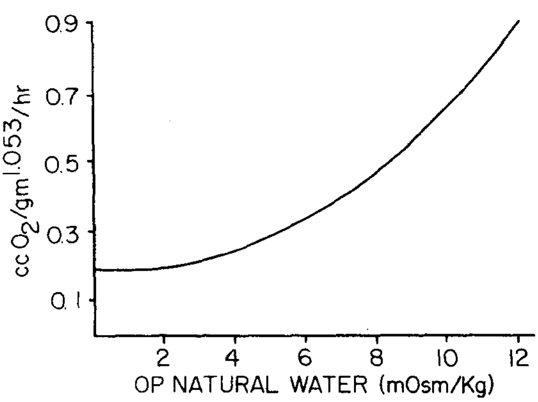

Fig. 2. Oxygen consumption of individual *Pimephales promelas* at various osmotic pressures for natural water.

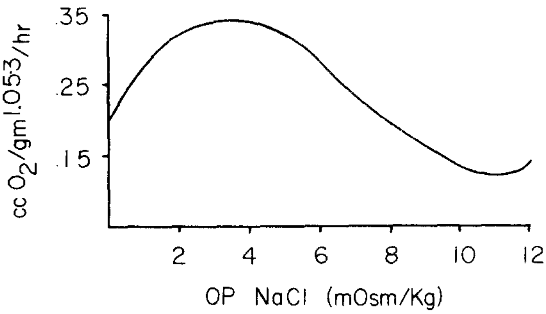

Fig. 3. Oxygen consumption of individual *Pimephales promelas* at various osmotic pressures adjusted with sodium chloride.

DISCUSSION

These studies have attempted to determine the influence of several environmental parameters on the metabolism of fathead minnows. It should be noted that within tolerable environmental ranges stressful conditions will elicit maximum metabolic rates while those conditions which would be considered optimal will not require the organism to expand massive amounts of energy in maintaining its existence.

pH

At pHs ranging from 8.2 to 9.2, fathead minnows use a large amount of energy to maintain their body functions. This, of course, assumes that activity is constant, which may not be the case. Since the water that these minnows inhabited was in a pH range of approx 7.2 to 8.0, and because most lakes have a pH range of about 6.5–8.5 (Welch, 1952), we might expect that this pH range is the most "comfortable". The 6.5–8.5 range may require the least amount of energy without causing detrimental effects to the fish. It could be argued that below a pH of about 6.5 and above a pH of about 8.0, minnows are experiencing a stressful situation. One possible cause could be an effect of the gill membranes ability to exchange oxygen and carbon dioxide (Welch, 1952). Beyond the upper limit of the "comfortable" range, the organism may be using less oxygen due to the deleterious effects to the respiratory mechanism, and that ultimate relationship to overall metabolic rate. The effect of pH on oxygen content and affinity are other possible avenues of explanation. An extreme influence of pH is indicated at approx 10.9 where mucus denaturation occurred.

We should note that other measured parameters (osmotic pressure and temperature) did vary somewhat between specimens and were not corrected for. If these parameters do influence oxygen consumption, as is shown by this and the previous study (Wares & Igram, 1978), and if variation due to activity did occur, a different correlation between oxygen consumption and pH might have been observed. The multiple regression analysis to follow this study, will take into consideration such possible interrelationships. It is possible that the aforementioned variability could be a partial cause of the low r^2 value obtained.

Osmotic pressure

We would expect that fish existing in fresh water would have to expend a considerable amount of energy to prevent inundation, and that as environmental osmolarity increased to near isotonicity, metabolic rate should decline. We would also suspect that as the environment was made hypertonic to the fish, the metabolic rate, as represented by oxygen consumption, would again rise. Several authors (Hoar, 1966; Rao, 1958; Prosser, 1973) substantiate these assumptions. Prosser (1973) also intimates that there is a close relationship between salinity and temperature and their effects on oxygen consumption.

Our results, obtained with variations in natural osmotic pressures, agree with the model as stated above. There is a small range of osmotic pressures over which the minnows exhibited a minimal rate of oxygen consumption, the rate increasing on either side of this range.

The effects of the sodium chloride induced changes in osmotic pressure are somewhat different. Oxygen consumption is elevated over the intermediate ranges, with decreasing rates at the extreme OP levels. Courtois (1976) found similar results in a study on *Gillichthys mirabilis*, where he attributed it to the possible induction of an osmoregulatory enzyme system (Na^+/K^+ ATPase) in response to salinity acclimation. Courtois (1976) suggested that as the induced enzyme approached a maximum concentration, the increased oxygen demands for enzyme induction would decrease and that the fish would osmoregulate at increasing efficiency. He thought this would account for the reduced oxygen demands by this species at salinities other than intermediate levels.

Light level

The effect of light intensity on oxygen consumption has not been widely studied in the past, particularly for fish. Woodhead (1956) and Jones (1956) conducted studies concerning effects of light intensity on activity. Both of these researchers used units of meter-candles, a photometric measurement concerned primarily with illuminosity and not intensity. Hoar (1966) states that photoperiod, which could well be related to intensity, has been shown to modify oxygen consumption in certain animals, assuming a mechanism involving neurosecretory centers and changing levels of hormones. Prosser (1973) agrees that photoperiod can affect metabolism.

There were some points in the studies of Woodhead (1956) and Jones (1956) that suggested a real relationship between oxygen consumption and light intensity. Both Jones (1956) and Woodhead (1956) used the minnow *Phoxinus phoxinus*, and we have no reason to suspect that a radical difference exists between that species and *Pimephales promelas*.

Jones (1956) suggested that although fish preferred shade, when cover was not available, they were more active (at greater light levels); further, the pattern of activity had no relation to temperature. Jones (1956) concluded that the minnows avoided high light intensities, and that there is an optimum range of intensity preferred.

Taking into consideration the observations of Jones (1956), it would seem a reasonable assumption that fish would consume greater amounts of oxygen at higher light intensities. This would indicate a direct relationship between light intensity and oxygen consumption, which correlates well with the results of this study.

Vinberg & Khartova (1953) reported greater oxygen consumption in young carp under illumination. Clausen (1936) showed that there are daily variations in oxygen consumption in different fishes, and some of the species studied showed maximum oxygen consumption at times during the day when light level was maximal. This again suggests a direct relationship.

In this study, data were taken at one period in the day, so that effects of activity due to time of day would be kept constant. The data still suggests an effect of light intensity on metabolism. The small r^2 value may be due to a masking of the light effect by other variables, including activity.

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