XLIX. THE RESPIRATORY EXCHANGE IN FRESH WATER FISH. III. GOLD FISH.

BY JOHN ADDYMAN GARDNER, GEORGE KING
AND EDWIN BOOTH POWERS.

*From the Physiological Laboratory, University of London,
South Kensington.*

(Received May 22nd, 1922.)

IN part I of this series of papers [Gardner and Leatham, 1914, 1] a detailed account was given of apparatus for measuring the respiratory exchange in fish, and measurements were recorded showing the influence of temperature, size of the animal, etc. on the respiratory exchange in the case of brown trout.

In this paper we give an account of experiments by the same method on gold fish.

METHOD.

Preliminary experiments showed that gold fish live at a much lower plane of metabolism than trout, and it was found necessary to modify slightly the procedure adopted with the latter animals.

In the case of trout the duration of the experiments varied from four to six hours. Gold fish, however, both at low and at ordinary temperatures use much smaller volumes of oxygen per hour, and it was found necessary to continue the experiments over periods of 24 hours in order to obtain accurate measurements. At higher temperatures more oxygen was used and satisfactory results could be obtained in experiments of six hours' duration.

In most of the 24 hour experiments it was not found practicable to continue the pumping of the air through the water during the whole period, owing to irregularities during the night of the electric power used in working the pumps, though in one or two experiments the pumping was continuous. Usually the experiment was commenced about 11 a.m. and the pumping of the air through the water bottle was continued until as late as convenient in the evening. The pump was started again early in the morning and continued until the end of the experiment. Experience showed that the absorption of oxygen was so slow that, with the large bulk of water used, the tension of the dissolved oxygen was not reduced sufficiently during the time the pumps were out of action to affect the fish. Oxygen, equivalent to that used during the 24 hours, was gradually added to the air above the water in the experimental bottle during the period before the cessation of pumping.

(4) Seven fish; 382 g.; variations 40–65 g. I.T. 6.2°, F.T. 6.3°. The fish had mild winter temperature prior to experiment. Duration 23.78 hours.

CO ₂	Initial	2167 cc.	Final	2230.3 cc.	Difference	+63.3 cc.
Oxygen	"	4321.9	"	4181.8	"	-140.1
Nitrogen	"	15469.4	"	15426.4	"	-43.0

Nitrogen error -0.28 %.

(5) Seven fish; 368 g.; variations 40–60 g. These fish had been in water covered with a film of ice for the previous three days. I.T. 5.7°, F.T. 6.05°. Duration 23 hours.

CO ₂	Initial	1648.6 cc.	Final	1781.5 cc.	Difference	+132.9 cc.
Oxygen	"	5216.4	"	5091.2	"	-125.2
Nitrogen	"	18894.4	"	18884.1	"	-10.3

Nitrogen error -0.054 %.

At medium temperatures.

(6) Seven fish; 355 g.; variations 35–60 g. I.T. 13.55°, F.T. 16.7°. Duration 24.25 hours.

CO ₂	Initial	2066.9 cc.	Final	2459.2 cc.	Difference	+392.3 cc.
Oxygen	"	4427.2	"	4020.7	"	-406.5
Nitrogen	"	16044.3	"	16017.6	"	-26.7

Nitrogen error -0.17 %.

(7) Seven fish; 355 g.; variations 35–60 g. I.T. 13.55°, F.T. 15.9°. Duration 23.25 hours.

CO ₂	Initial	2123.9 cc.	Final	2392.0 cc.	Difference	+268.1 cc.
Oxygen	"	4413.4	"	3976.3	"	-437.1
Nitrogen	"	15966.4	"	15931.4	"	-35.0

Nitrogen error -0.22 %.

At higher temperatures.

(8) Seven fish; 370 g.; variations 45–62 g. I.T. 21.4°, F.T. 20.6°. Duration 23.18 hours. In this experiment the valves of the pumping apparatus were out of order and the air could not be pumped through the water. At the end the water in the experimental bottle had a strong faecal smell.

CO ₂	Initial	1518.4 cc.	Final	2256.5 cc.	Difference	+738.1 cc.
Oxygen	"	5098.7	"	4521.2	"	-577.5
Nitrogen	"	18551.2	"	18519.1	"	-32.1

Nitrogen error 0.17 %.

(9) Seven fish; weight 361 g.; variations 45–63 g. I.T. 20.7°, F.T. 20.4°. Duration seven hours. At the end no objectionable smell was noted.

CO ₂	Initial	1649.1 cc.	Final	1855.2 cc.	Difference	+206.1 cc.
Oxygen	"	4640.8	"	4354.0	"	-286.8
Nitrogen	"	16805.0	"	16819.9	"	+14.9

Nitrogen error +0.088 %.

The results of these experiments are given in Table I.

Table I.

No. of exp.	Average weight of fish used in g.	Volume of oxygen consumed per fish per hour in cc. at 0° and 760	Volume of CO ₂ produced per fish per hour in cc. at 0° and 760	Volume of oxygen consumed per kilo of fish per hour in cc. at 0° and 760	Volume of CO ₂ produced per kilo of fish per hour in cc. at 0° and 760	Respiratory quotient
At low temperature:						
(1)	51.7	1.225	0.684	23.70	13.23	0.56
(2)	49.7	0.574	0.723	11.56	14.55	1.26
(3)	50.0	0.747	0.674	14.91	13.45	0.98
(4)	54.5	0.842	0.380	15.42	6.97	0.45
(5)	52.5	0.778	0.825	14.79	15.70	1.06
Mean		0.833	0.657	16.07	12.78	
At medium temperature:						
(6)	50.7	2.395	2.309	47.22	45.54	0.97
(7)	50.7	2.686	1.647	52.96	32.48	0.61
Mean		2.541	1.978	50.09	39.01	
At higher temperature:						
(8)	52.8	3.560	4.550	67.35	86.08	1.28
(9)	51.6	5.853	4.207	113.50	81.55	0.72
Mean		4.706	4.379	90.43	83.81	

INFLUENCE OF TEMPERATURE.

It will be seen from Table I that the volume of oxygen consumed per fish, or per kilo of fish, increases with the temperature and very roughly in proportion to the temperature.

We should scarcely expect to find any exact proportion in experiments on the living animal, more especially as, owing to the long period over which the work extended, different sets of fish were used, and some latitude must be allowed for individual idiosyncrasy. Further in most of the experiments it was necessary to keep the animals in the experimental bottle for about 24 hours and during some hours the pumping of air was discontinued, so that during some part of the experiment the oxygen tension in the water would be below saturation. Experiments 8 and 9 at higher temperatures need some comment, as they show marked difference in the oxygen absorption, though most of the fish used were the same in each.

In experiment 8, which was of 24 hours' duration, the valves of the apparatus went wrong at the beginning, so that it was impossible to pump the air of the bottle through the water. Consequently the oxygen tension in the water progressively decreased, and at the end the partial pressure of the oxygen in the water was only 0.583 % of an atmosphere. At the end it was also noticed that the water had an objectionable faecal smell, a condition not found in any of the other experiments. It seemed probable therefore that the oxygen consumption figure was below normal. The experiment was therefore repeated (No. 9) and the duration was reduced to seven hours. Pumping was continuous. The oxygen figure is markedly higher than in No 8, and the respiratory quotient approximately normal for an unfed animal.

In the experiments at low and at normal temperatures, owing to the relatively slow oxygen absorption of the fish, it did not seem likely that the

small reduction of the oxygen tension in the water during the non-pumping stage of the experiment would have much effect.

To test this, however, we made the following experiment at a moderate temperature keeping the oxygen tension below normal during the whole time.

(10) Seven fish; weight 329 g.; variations 22–65 g. I.T. of water 16.8°, F.T. 16°. The water had been previously partially denuded of oxygen and the gas over the water was air and nitrogen. Duration six hours. The partial pressure of the dissolved oxygen was found to be at the beginning 6.17 % and at the end 2.69 % of an atmosphere.

CO ₂	Initial	436.0 cc.	Final	510.1 cc.	Difference	+ 74.1 cc.
Oxygen	"	2301.9	"	2168.2	"	- 133.7
Nitrogen	"	23818.5	"	23847.6	"	+ 29.1
Nitrogen error + 0.12 %.						

Oxygen absorbed per fish per hour 3.114 cc. or per kilo of fish per hour 66.26 cc. Carbon dioxide evolved per fish per hour 1.726 cc., or per kilo per hour 36.72 cc. The respiratory quotient is 0.55.

At the temperature used the oxygen absorption should be a little higher than the mean of experiments 6 and 7. This is evidently the case, and we may conclude that the non-pumping interval in the experiments at low and at medium temperatures did not appreciably affect the result.

COMPARISON OF THE OXYGEN REQUIREMENTS OF TROUT AND GOLD FISH.

In Table II the oxygen requirements of trout and gold fish, at various temperatures, are compared. The gold fish were 5 to 6 inches in length, and the sets of trout 4 inches and 8 inches respectively, but comparisons in terms of length are somewhat imperfect, owing to the difference in shape of the two kinds of fish. We were unable to obtain gold fish of the same average weight as the larger trout, in sufficient number. A glance at the table will

Table II. *Comparison of oxygen consumption of gold fish and trout.*

	4 inch trout, average weight 23 g.		8 inch trout, average weight 102 g.		5 to 6 inch gold fish, average weight 51 g.	
	Per fish per hour	Per kilo of fish	Per fish	Per kilo	Per fish	Per kilo
4°–7°	2.05	89.04	10.48	102.53	0.83	16.07
13°–16°	2.82	117.40	17.84	192.36	2.54	50.09
20°–22°	4.63	213.80	19.57	204.24	4.71	90.42
25°	5.64	258.87	—	—	—	—

show that the gold fish live at a much lower plane of metabolism than trout, and require much less oxygen. They also appear to react to temperature over a wider range than trout. At temperatures round 16° gold fish use about three times as much oxygen as at 4° to 7°, whereas the 8 inch trout use about double. A further rise in temperature from about 16° to between 20° and 22° again doubled the oxygen used by the gold fish, but caused only a small increase in the case of trout. It would appear at first sight that in the case of the large trout the organism ceases to react to rise of temperature about

the limit of 16° to 17° , but that in the case of gold fish this limit is higher, for the ratio of oxygen consumption of gold fish to trout at 4° to 7° is about 1:6, at about 16° 1:4, and at 20° to 23° nearly 1:2. It is probable, however, that this difference in reactivity to temperature is more apparent than real, for it has been shown [Gardner and Leatham, 1914, 2] that trout can live and keep well for long periods at a lower level of oxygen partial pressure than that corresponding to full saturation, and it is well known that gold fish flourish at very much lower levels of saturation; in addition the large trout were somewhat restricted in their movements in the experimental bottle compared with the smaller animals, and were consequently less favourably situated for assisting the pumping of water through the gills by swimming movements. If we make the assumption that a fish absorbs the whole of the oxygen from the water passing through its gills, then calculating on the basis of Winkler's figures [1905] for the oxygen content of water saturated with air at various temperatures, a 4 inch trout at 7° to 8° would need to pump about 4 cc. per minute through its gills, while at 21° he would need about 12.4 cc. per minute and at 25° , 16 cc. per minute. On the same basis an 8 inch trout would need to pump at 6° , 20 cc. per minute, and 16° , 44 to 45 cc. The above assumption is perhaps scarcely warrantable, so that these figures must be regarded as minimum values. It is therefore perhaps not surprising that the large fish should apparently cease to react to increases of temperature at a lower temperature than the small fish.

Another factor which appears to bear on the difference between trout and gold fish in this respect is that gold fish are able to bear with impunity higher temperatures than trout. As was shown in the paper referred to above [1914, 1] temperatures round about 25° appear to be dangerous or fatal to trout. Measurements of respiratory exchange were successfully carried out on 4 inch trout at 25° , but on attempting to determine the oxygen absorption for 8 inch trout at this temperature, of the three fish used in the experiment, one died in about two minutes, though the water was fully oxygenated, and the other two turned over on their backs in about ten minutes, and would no doubt have died, but on adding cold water they recovered completely and rapidly, and appeared to be quite well the next day. This result was not due to any sudden change of temperature, as the fish were carefully and gradually warmed up beforehand during the course of one hour. In another experiment four 8 inch fish were accidentally plunged into well-oxygenated water at 33° . The fish gave a few violent leaps and collapsed as one might perhaps imagine a warm-blooded animal doing on falling into boiling water, and were all quite dead in under one minute. The water was afterwards found to be quite frothy, as though it contained some saponaceous material. Some experiments were made with gold fish to ascertain the maximum temperature compatible with life. A strong healthy gold fish (about 50 g.) was placed in a large earthenware basin of water at 20° . After 15 minutes warm water was carefully added, with good stirring, until the temperature rose to 25° . At intervals of 10-15

minutes more hot water was gradually added, and the temperature very gradually increased. At 30° the fish was very active, swimming about more rapidly and continuously than at lower temperatures, but beyond this showed no apparent sign of distress, though the breathing, as one would expect, was rather rapid. At 35° the fish apparently died without any struggle, remaining on his side at the surface, the mouth being closed. No sign of life being observed after ten minutes at this temperature, the water was then gradually cooled down to 17°. After about one hour the fish was observed to be breathing feebly. It then began to recover more rapidly; it was put into the store tank outside, and the next day appeared to have completely recovered.

It would seem from these experiments that trout can live in water up to a temperature of from 20–25°, but gold fish can exist without apparent harm up to at least 30° or even higher. This result is, we believe, in accordance with the geographical distribution of these fish. As far as we are aware trout are never found in tropical rivers, except such as have a snow mountain source.

RESPIRATORY QUOTIENT.

We are not yet able to explain the variations noted in the respiratory quotient, particularly the very low values observed with trout at low temperatures, but a careful examination of our experimental results has convinced us that the variations cannot be attributed to experimental error.

Experiments are in progress which we hope will throw light on this point.

We take this opportunity of expressing our thanks to the Government Grant Committee of the Royal Society for aid in carrying out this work.

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