METABOLIC RATES OF TROUT FRY FROM SWIFT AND SLOW-RUNNING WATERS

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RECENT studies on the respiration of fresh-water animals have shown that certain species of ephemerid nymphs and trichopterid larvae inhabiting swift streams have a higher oxygen consumption than other species, comparable in size, which live in still waters, the measurements being made under identical conditions (Fox, Simmonds and Washbourn, 1935). Moreover, within one species of crustacean, *Asellus aquaticus*, individuals from rapid water have a higher metabolic rate than those from slow water (Fox and Simmonds, 1933). The investigation reported below was undertaken to find out whether trout would show a similar phenomenon.

The experiments were made at the Bibury Trout Farm, Gloucestershire,[1] using the fry of the brown trout (*Salmo fario*). Two lots of 750 fry each, which had absorbed the yolk sac a fortnight previously, were selected at random and placed in each of two experimental tanks in the open air. These wooden tanks, in which the fish remained for nearly three months, were 6 × 4 × 2 ft. in size. They were painted inside with non-toxic paint and were fitted with netting, screens, etc., according to the usual practice in fish culture. Water, coming direct from a spring, flowed rapidly through one of the two tanks, and the fish orientated themselves into the direction of the current. In the second tank the flow was very slow and the fish showed no orientation except just at the inflow.

The temperature of the spring water did not vary from 10° C. and this was the temperature in both tanks throughout the experiment. To ensure this constant temperature, the slow-water tank was jacketed with an outer box, through which the spring water flowed rapidly.

The oxygen content of the water in the tanks was not measured, but it is now known (Washbourn, unpublished data) that the rate of oxygen consumption by trout is independent of the oxygen content of the water through a wide range.

The trout fry were placed in the two tanks on March 15th, and remained in them until June 5th. The health of the fish was good throughout, losses from disease being rare. They were fed on a mixed diet of horse liver, egg and commercial meal, and as far as was possible the amount of food given was the same in each tank. The numbers of fish slowly diminished, owing to losses which were chiefly caused by the cannibalism of the larger fish. To prevent this as far as possible, it was necessary

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to remove the largest fishes, as well as any others which were actually seen eating their fellows.

At the end of the period of nearly 3 months in the tanks, the oxygen consumption of the fish was measured. In order to avoid complications due to sensitivity to handling, and to abolish the risk of excitement affecting the experimental results, the fish were narcotised before the measurements were begun. It is known (Krogh, 1914) that urethane is a suitable narcotic for fish, and that by choosing the correct strength of solution it is possible to keep fish in a standard state of narcosis for long periods. Experiments made on the trout fry showed that 0·2 per cent. urethane in Bibury spring water was the most suitable strength of narcotic, and that with a large majority of the fish a state of narcosis was caused in which all spontaneous movements were abolished, the fish remaining motionless for a considerable period, except for the opercular movements. Tests showed that trout fry could stand this strength of narcotic for a considerable time: out of a batch of fifteen kept for 6 hours in the narcotic, fourteen recovered within 1 hour. For the oxygen consumption measurements they were narcotised for 3 hours only.

Observations were made on the stages of narcosis, and on differences in the sensitivity of individuals. There were found to be three phases. The first result of putting trout fry into 0·2 per cent. urethane is a marked drowsiness. The fish do not swim as actively as the controls, nor for such a long period, and they are not stimulated by touch. The second phase is one of increased activity and sensitivity. The fish swim continuously for a long period, and they are very sensitive to touch and mechanical shock. In this period, the fish appear to swim blindly, and they may swim continuously in a circular course on the floor of the tank. The third phase is one in which spontaneous movements vanish, and the fish remain on the bottom of the tank motionless except for the movements of the opercula. The sensitivity of individuals varies, and while with the strength of narcotic used the large majority of fishes reached the third phase, and remained in that state for a long time, a few stayed in the active phase, and a few died.

In order to avoid deaths taking place during the measurement of oxygen intake, it was necessary first to select those unnarcotised fishes which had the most active opercular movements. Experience showed that such fish would live for a considerable period under the narcotic. This selection ensured that all fishes were subsequently as nearly as possible in the same condition of narcosis. Careful observations were made to see whether there was any detectable difference in the sensitivity of the batches of fish used for the separate experiments, but none could be found.

The fish for the respiration measurements were removed from the tanks in a small net and carried in a bucket to the hatching house, in which the measurements were made. They were narcotised in 10-litre glass jars with 0·2 per cent. urethane solution in Bibury water, in which they remained for $1\frac{1}{2}$ hours before an experiment began. At the end of this time a batch of ten was selected for each experiment, and was placed in a 1-litre conical flask containing urethane solution of known oxygen content. The flask was closed with a rubber bung and then remained for $1\frac{1}{2}$ hours standing in a thermostat at 10° C. Every 5 min. the flask was turned sharply upside down to stir the water. At the end of the experiment the oxygen content of the water was again measured, and the fish were killed and weighed after the excess water had been removed from them by a standard procedure. The oxygen content of the water was measured by the Winkler method. (The *p*H of the water was determined colorimetrically, and it was found that during experiments the maximum change in *p*H was from 7·8 to 7·4.)

The results of the experiments are shown in Table I, the oxygen consumption being given in c.c. at N.T.P. per kg. wet weight of fish per hour. The standard deviations of the means show that the respiration of the swift-water fish (116 ± 4·5) is significantly higher than that of the fish from slow water (91 ± 7·0). The case of the trout is therefore parallel to that of *Asellus* cited above.

Table I. *Oxygen consumption of trout fry*

Habitat	Exp. No.	Wet weight of 10 fishes gm.	Oxygen consumption c.mm./gr./hour
Swift-water tank	1	7·1	108
	2	7·0	122
	3	7·5	144
	4	7·4	129
	5	7·5	107
	6	7·5	115
	7	4·4	114
	8	4·3	97
	9	6·2	96
	10	8·2	126
			Mean 116 ± 4·5
Slow-water tank	1	7·2	85
	2	6·2	152
	3	4·4	83
	4	4·0	69
	5	7·7	95
	6	5·6	87
	7	5·2	71
	8	5·3	94
	9	5·6	83
	10	7·1	94
			Mean 91 ± 7·0

SUMMARY

Trout fry were reared for 3 months in two tanks at the same temperature but differing in the rate of flow of water. The oxygen consumption of the fish was measured at the end of this period, under standard conditions. The fish from swift water were found to consume significantly more oxygen than those from slow water.

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