XXII. RESPIRATORY EXCHANGE IN FRESH-WATER FISH.

PART VI. ON PIKE (*ESOX LUCIUS*)

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PIKE form a small family of soft-rayed fishes pretty generally distributed over the rivers and lakes of Europe, Northern Asia and North America. In the old world one species only—*Esox lucius*—is common. Its eastward range is not known, as far as we are aware, but it extends into Lapland in the north and into central Italy in the south; it appears however to be absent from the Iberian Peninsula. It has an elongate rather compressed body covered with small scales, a long head with long and spatulate snout, and a very large mouth armed with strong teeth in the jaws and bands of smaller teeth in the palate and tongue. The teeth point backwards or can be depressed so as to offer no obstruction to any object entering the gape, but prevent its withdrawal in the opposite direction. The pike is the most voracious of fresh water fishes, and many writers have compared it to the shark with regard to the quantity of food it consumes. It leads rather a sedentary than a roving life, and prefers lakes and the sluggish reaches of rivers to strong currents or agitated waters. The dorsal and anal fins are placed far back in the tail, thus greatly increasing the propelling power of the fish, and though relatively poor swimmers pike are excelled by no other fresh-water fish in rapidity of motion when by a single stroke of the tail, they dart upon their prey or out of reach of danger. They appear to be very hardy and we found they could stand confinement remarkably well.

On account of their sluggish disposition and yet great voracity it seemed of interest to determine their oxygen requirements. The fish used for experiment were about 12 inches in length and varied in weight from 110 to 160 g. When placed in the tank they remained very sluggish during the experimental period and though there were plenty of minnows in the tank, the pike did not exhibit their usual voracity, and specimens killed from time to time showed little or no food in the stomach. Probably they were scared by the necessary handling.

The method adopted was that fully described in former papers of this series [1914, 1 and 1922, 1, 2].

EXPERIMENTAL.

At low temperature. Four fish were taken weighing respectively 150, 110, 100 and 140 g. Total weight 500. Initial temp. of water 5·7°, final temp. 6·1°. Duration of experiment 18 hours 57 minutes. 275 cc. commercial oxygen were added during the experiment.

Total free and combined CO_2	at beginning 1513·2 cc.	at end 1673·6 cc.	diff. 160·4 cc.
„ oxygen	„ 5208·1	„ 4963·8	„ 244·3
„ nitrogen	„ 18975·2	„ 18973·6	„ 1·6

Error in nitrogen 0·0084 %.

At medium temperature. Five fish, 125, 105, 145, 110 and 155 g. respectively. Total 640 g. Initial temp. of water 11·2°, final temp. 13·7°. Duration of experiment 4 hours 17 minutes. 275 cc. oxygen added during experiment.

Total free and combined CO_2	initial 2164·5 cc.	final 2297·6 cc.	diff. 133·1 cc.
„ oxygen	„ 4362·5	„ 4181·6	„ 180·9
„ nitrogen	„ 15655·9	„ 15658·9	„ 3·0

Nitrogen error 0·0199 %.

Five fish total weight 595 g. Initial temp. of water 16·6°, final temp. 16·65°. Duration of experiment 4 hours 14 minutes. During the experiment 275 cc. oxygen added.

Total free and combined CO_2	initial 1874·4 cc.	final 2039·9 cc.	diff. 165·5 cc.
„ oxygen	„ 4534·8	„ 4341·2	„ 193·4
„ nitrogen	„ 16267·1	„ 16275·0	„ 7·9

Nitrogen error 0·048 %.

At high temperature. Five fish, 145, 155, 135, 160 and 110 g. respectively, total 705 g. Initial temp. of water 22·9°, final 22·2°. Duration of experiment 4 hours 8 minutes. 275 cc. oxygen added.

Total free and combined CO_2	initial 1781·2 cc.	final 2026·4 cc.	diff. 245·2 cc.
„ oxygen	„ 4514·3	„ 4215·4	„ 298·9
„ nitrogen	„ 16419·8	„ 16398·0	„ 21·8

Nitrogen error 0·13 %.

These results are gathered together in the following table.

Table I.

Temperature °C.	Oxygen consumed per fish per hour cc.	Oxygen consumed per kilo of fish per hour cc.	CO_2 evolved per fish per hour cc.	CO_2 evolved per kilo of fish per hour cc.	Respiratory quotient
5·7– 6·1	3·06	24·44	2·01	16·08	0·66
11·2–13·7	8·45	65·99	6·22	48·56	0·74
16·6–16·65	9·14	76·79	7·82	65·71	0·86
22·9–22·2	14·46	102·58	11·87	84·18	0·82

In this case again the oxygen consumed per fish is approximately proportional to the rise in temperature, and if the oxygen values are plotted against temperature the curve is nearly a straight line.

The respiratory quotients at all temperatures were approximately normal for carnivorous animals.

Table II. *Oxygen consumption per kilo of fish.*

Temperature °C.	Pike	Gold fish	Eels
5°–6°	24·44	16·07	9·28
about 16°	76·79	50·09	44·40
22°	102·58	83·81	61·29

On comparing the oxygen consumption of pike with that of eels and gold fish, it will be seen from Table II that at the various temperatures pike require more oxygen than gold fish in the ratio of about 3 : 2, and that gold fish in this respect occupy a position midway between pike and eels.

Quantity of oxygen in the water at the asphyxial point for pike.

It seemed of interest to determine the behaviour of pike under reduced oxygen tension and measure the quantity of oxygen in the water at the asphyxial point.

Experiments were carried out at a medium temperature and the apparatus and method fully described in Part II of this series of papers [1914, 2] were used. No experiments were made at low temperatures as it did not seem likely that it would be possible to reduce the oxygen in the water to the asphyxial tension within a reasonable time, and the fish at our disposal were too large for the small apparatus used for gold fish in Part IV [1922, 2].

A constant stream of nitrogen was passed through the experimental bottle during the night to reduce the oxygen tension in the water and the fish were introduced the following morning.

Four fish weighing respectively (1) 90, (2) 150, (3) 152 and (4) 120 g. were selected. Two fish were placed in the bottle at 10·58 a.m., the temperature of the water being 15·3°. Both fish remained inactive at first and the respiration rate was about 77 per minute. Minute bubbles of gas were seen to rise occasionally from the smaller fish, but no sign of distress was apparent in either and movement was only occasional. At 11.40 a.m. the other two fish (3 and 4) were introduced, and nitrogen was circulated through the water by the pumping apparatus. The bubbling of fresh nitrogen through the water sampling tube and the pumping through the spraying tube were carried on simultaneously.

At 12.45 p.m. one of the fish began to show marked activity and was seen to rise to the surface. All the fish then became more active and rose to the surface frequently. At 1.20 p.m. one of the fish gave a violent leap out of the water, which was repeated a little afterwards. The frequency of respiration of one of the fish at 1.45 p.m. was 60–70 per minute. Increased activity, accompanied by vigorous leaps out of the water, was observed until about 2.45 p.m., after which the fish again became sluggish and their movements more spasmodic with longer intervals of rest. At 3.45 p.m. one fish gave a violent leap and then turned over. After some spasmodic movements the fish settled on its back, with occasional convulsive gasps. The other fish showed signs of getting into the same condition. At this point a sample of water was withdrawn for analysis, and the current of nitrogen then replaced by a rapid current of oxygen. At 4.45 p.m. the fish which had been most affected again assumed a normal position. On removal to the outdoor tank the fish appeared to have quite recovered and continued perfectly healthy for many weeks, and were ultimately killed for other purposes.

Analysis of sample of water, the temperature of which when collected was 14·1°.

The gas dissolved in the water sample (45·995 cc. of water) was pumped out in the usual way. It exerted a pressure of 10·225 mm. Hg at 11·64° and constant volume 36·62 cc.; after shaking with 40 % KOH it exerted a pressure of 1·83 mm. Hg at 12·08°; and after shaking with alkaline pyrogallol, a pressure of 1·80 mm. Hg at 12·60°. The volumes of CO_2 (free and combined), oxygen, and nitrogen dissolved per litre of water were therefore 84·38 cc., 0·334 cc., and 18·025 cc. respectively, measured at S.T.P. The coefficient of absorption of O_2 in water at 14·1° is 0·03479.

Hence the tension of dissolved oxygen was $\frac{0\cdot334}{10 \times 0\cdot03479} = 0\cdot96\ \%$ of an atmosphere, *i.e.* 7·30 mm. Hg.

Evidently pike, like gold fish and eels, can exist at tensions considerably below normal without harm.

Limits of temperature within which pike can live.

In order to determine the highest temperature at which pike can live, a fish *A* weighing 150 g. and another *B* weighing 107 g. were placed in a tub of cold water at 11°, and the temperature was very gradually raised to 18–19° by careful addition of warm water. The water was kept fully oxygenated by spraying oxygen through by means of a circular lead coil perforated with fine holes. The temperature was very gradually raised, but no sign of discomforture was observed until the temperature had reached 27°. The rates of respiration noted at various temperatures were as follows:

Temperature	11°	18°	22°	26°	27°	29°
Respiration rate	56	47	45	40	55	63

At 27° the respirations were markedly deeper and the fish became more active. Movements became slightly convulsive in the neighbourhood of 30°, and at this temperature both fish turned over. The fish were then immediately removed to cold water, and on return to the outside tank quickly revived and appeared to have suffered no harm. They were alive and healthy many weeks after the experiment.

In our experience pike are remarkably hardy in confinement, and consequently very suitable for experiments such as have been described, and, as we hope to show later, for experiments on the effects of toxic substances.

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