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EFFECTS OF TEMPERATURE AND BODY WEIGHT ON VENTILATION VOLUME OF COMMON CARP (*CYPRINUS CARPIO* L.)

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Background. Ventilation volume is a parameter used mainly for determining oxygen consumption of fish. The aim of the present work was to determine the ventilation volume of carp, under conditions of pure, aerated water.
Material and methods. Stroke volume and breathing rate of carp representing three size groups (258.7 ± 40.1 g, 449.3 ± 39.6 g, and 663.2 ± 32.3 g) were studied within the temperature range of 10–25°C.
Results. At 10°C the stroke volume of carp weighing 200–300 g was on average 2.25 ± 0.63 ml per 1 breath. This parameter in fish weighing 400–500 g was 2.70 ± 0.12 ml per 1 breath, while in fish attaining 600–700 g it amounted to 3.22 ± 0.41 ml per 1 breath. The breathing rate of all size groups ranged from 46.2 to 47.4 ± 8.51 cycles per min. A statistically significant increase of the stroke volume was recorded in all size groups at 15°C. At 20°C the increased stroke volume was accompanied by accelerated breathing rate. The temperature increase from 20 to 25°C did not cause any further increase of either breathing rate or stroke volume.
Conclusion. The temperature-related regulation of the ventilation volume in carp is a two-step process. At 10–15°C the increased water volume pumped through the gills was achieved by an increased breathing depth (stroke volume). A further increase of the ventilation volume at 15–25°C resulted from acceleration of the breathing rate.

Key words: fish, common carp, *Cyprinus carpio*, respiration, ventilation volume, stroke volume, breathing rate

INTRODUCTION

Fish respiratory function is controlled by the medullary respiratory centre, which generates rhythmical stimuli responsible for the functioning of branchial system (Schade and Weiler 1959, Shelton 1970, Fukada 1975). The centre receives information

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from branchial O_2 and CO_2/pH chemoreceptors that are sensitive to the concentration of respiratory gases concentration in both blood and water (Burleson and Milsom 1995, Sundin et al. 2000), from proprioceptors sensing changes in respiratory muscles activity (Ballintijn and Roberts 1976, Ballintijn and Alink 1977), and from mechanoreceptors that measure the speed of water flow through the gill (Burleson and Milsom 1993, 1995).

Parameters of branchial system activity, i.e. breathing rate, stroke volume (volume of water transported with a single movement of gill covers), and ventilation volume (volume of water transported through the gill system during 1 hour) have been used mainly in measuring fish oxygen consumption (Hughes 1984, Yamamoto and Hashimoto 1988, Glass et al. 1990, Yamamoto 1991).

Information on ventilation volume may also be of use in investigating how chemicals dissolved in water affect the fish's organism and what is the rate they are absorbed through the gills (Kłyszejko and Ciereszko 1999). These particularly apply when the same water goes repeatedly through the gill system due to a small capacity of the tank or densely stocked fish (e.g. in live-fish transport).

The common carp, *Cyprinus carpio* Linnaeus, 1758, as a farmed fish, is subjected to a range of treatments in which chemicals are administered to the water (drugs, disinfectants, tranquillizers, etc.), and also represents a common model for toxicological tests.

This study was aimed to determine the ventilation volume of carp in clean, aerated water, with regard to temperature and body weight.

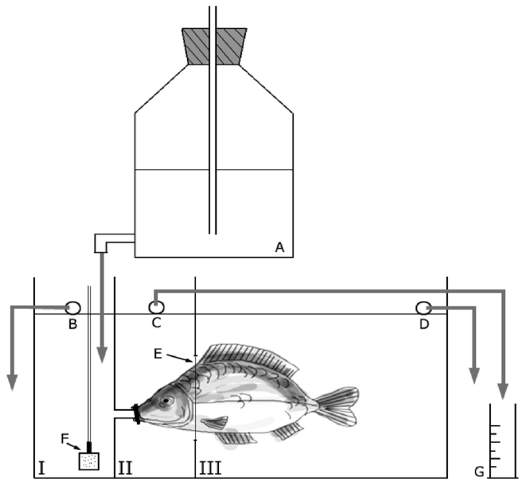
MATERIAL AND METHODS

The experiments were carried out on 120 carp specimens obtained from a cage culture placed in the cooling-water discharge canal of the Dolna Odra power station near Szczecin, Poland.

The experimental design consisted of 3 groups (40 fish each) of carp of individual body weights 200–300, 400–500, and 600–700 g. The mean body weights within the groups were: 258.7 ± 40.1 g, 449.3 ± 39.6 g, and 663.2 ± 32.3 g, respectively. Before the experiments, the fish had been acclimated to the temperatures of 10, 15, 20, and 25 ± 1.5°C (10 fish from each size group) for 6 days. The acclimation took place in thermoregulated 200-l aquaria, filled with filtered and aerated tap water of pH 7.8–8.2.

Oxygen dissolved in the water was measured following the Winkler method. The mean oxygen concentrations at 10, 15, 20, and 25°C were 12.04, 10.61, 9.72, and 8.65 mg $O_2 \cdot l^{-1}$, respectively. Each fish was used in the experiment only once. The experiments were carried out using an experimental apparatus presented in Fig. 1. The apparatus consisted of a glass tank divided into 3 chambers, I (10-l capacity), II (10 l), and III (20 l), and a Marriott bottle of 25 l used as a water reservoir. In the partition wall between chambers I and II of the aquarium, there was a round, 8-mm diameter opening with a stiff pipe fixed in it, protruding into the space of the chamber II. In the wall separating chambers II and III, there was an elliptical opening (15 × 9 cm) with

an elastic rubber membrane fixed around the edge. The outlets from each chamber were placed at the same level so as to maintain constant hydrostatic pressure in the aquarium throughout the experiment. A set of silicon mouthpieces adapted to various sizes of fish mouths was an additional part of the experimental apparatus.



A, Marriott bottle; B, C, D, outlets; E, rubber membrane; F, aeration; G, gradnate cylinder; I, II, III, aquarium chambers

Fig. 1. Diagram of the experimental apparatus

The experimental protocol was as follows: a mouthpiece was placed in the fish's mouth and fastened with an elastic band around the lips. The fish was placed in the experimental tank with the mouthpiece fixed on the end of the pipe in chamber II. Due to such placement, the fish took the water from chamber I, its head remained in chamber II, while its body (fastened behind the head with the elastic membrane) was in chamber III. The water was supplied from the Marriott bottle to chamber I in a quantity slightly exceeding the quantity taken by the fish. The excess flowed out spontaneously through the outlet of chamber I. The water pumped through the gill system flowed through the outlet of chamber II and was collected in the measuring glass. Restricted water flow between chambers II and III (due to the sealing membrane) increased precision of the measurements, which were begun 1 h from the moment of placing a fish in the experimental aquarium.

Stroke volume (volume of water per 1 breath, in ml) was calculated on a sample collected during 10 minutes. Such time-period was accepted as the basis for measurements because carp display temporary changes in the breathing rate (Peyraud and Serfaty 1964). Also, the mean breathing rate (number of gill cover movements per 1 min) was counted during 10 min.

Ventilation volume (volume of water per hour, in litres) was calculated as a quotient of the stroke volume and the breathing rate. Ventilation volumes by size

groups of fish were also converted to relative values (volume of water per hour per 1 kg of fish body weight).

All the results were statistically processed using the t-test.

RESULTS AND DISCUSSION

Oxygen consumption by fishes is a species-specific trait, and its increase within a species is accompanied by an increase in ventilation volume (Winberg 1956, Brett and Groves 1979, Hughes 1984, Yamamoto and Hashimoto 1988). In the case of carp, 70–75% of the total gas exchange is done through the gills, hence the quantity of water pumped through the gill system indirectly indicates current respiratory demand as well as the aerobic conditions in the environment (Yamamoto and Hashimoto 1988).

The present experiments demonstrated that in clean, aerated water, at 10°C, the stroke volumes of carp of individual body weight of 200–300 g, 400–500 g, and 600–700 g, were 2.25 ± 0.63 ml, 2.70 ± 0.12 ml, and 3.22 ± 0.41 ml per 1 breath, respectively. Breathing rate in all the size groups was similar and ranged from 46.2 to 47.4 ± 8.51 cycles per min (Fig. 2). These figures were used as reference values in estimation of significance of changes resulting from a water temperature increase. At 15°C, a statistically significant increase in stroke volume was observed in all size groups. At 20°C, the increased stroke volume was accompanied by accelerated breathing rate. Increasing the temperature from 20 to 25°C did not result in any further increase, neither in breathing rate nor in stroke volume.

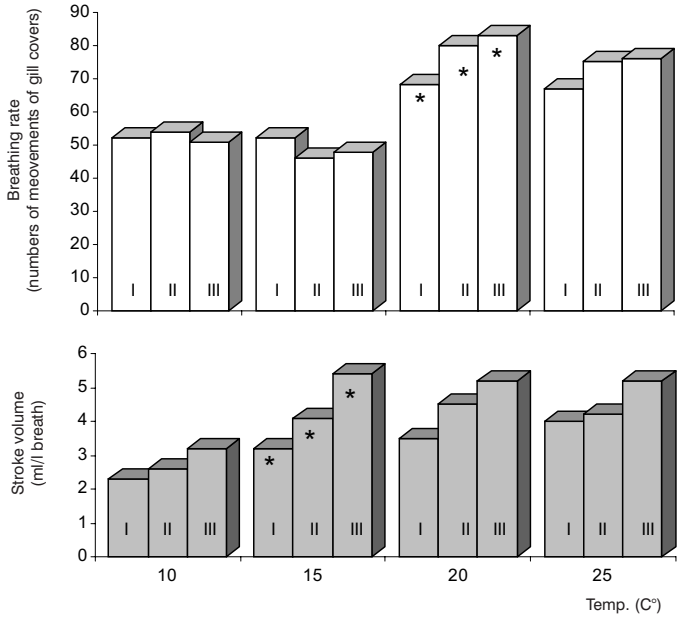


Fig. 2. Effect of water temperature on breathing rate and stroke volume of carp. * Statistically significant differences in relation to the values of lower temperature ($P < 0.05$)

The product of breathing rate and stroke volume revealed that the quantities of water transported through the gills at 10°C for fish of 200–300 g, 400–500 g, and 600–700 g, were 6.9, 8.7, and 9.6 l per hour, respectively, whereas at 25°C the quantities increased to 15.0, 22.7, and 25.7 l per hour, respectively (Fig. 3, row A).

Studies by Yamamoto (1991) revealed that under a low level of stress and at a constant temperature, the respiration rate of common carp remains at a constant level, while the ventilation volume depends on stroke volume only and is directly proportional to the unit body weight of a fish. Our experiment has confirmed the findings by Yamamoto (1991), however, only in the range of low temperatures (10–15°C). Above 15°C up, a temperature growth did not result in any further increase of stroke volume. This probably indicates that the upper limit of a carp's respiration depth, which is shaped by the anatomy of the gill system, has been reached. At temperatures of 15–25°C, an increased ventilation volume was due to increased respiration rate only (Fig. 3, row A).

It has been known that higher metabolic rate and increased oxygen demand can be observed in ontogenetically younger specimens of lower individual body weight. It is illustrated in Fig. 3 (B), where empirical ventilation volumes of fish of various body weights were calculated per 1 kg of body weight.

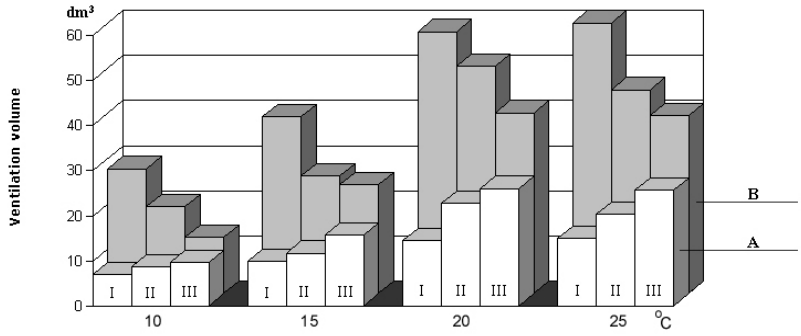


Fig. 3. Effect of water temperature on ventilation volume of carp; I, individual body weight 200–300 g; II, individual body weight 400–500 g; III, individual body weight 600–700 g; A, absolute ventilation volume ($l \cdot h^{-1}$); B, relative ventilation volume ($l \cdot h^{-1} \cdot kg^{-1}$)

The results of the experiments demonstrated that regulation of the ventilation volume in carp related to changes in temperature was a two-stage process. In the range of 10–15°C, changing the depth of breath (stroke volume) controlled the quantity of water pumped through the gill system, while in the range 15–25°C, the stroke volume reached its maximum level and further increase in ventilation volume was due to an accelerated breathing rate.

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