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## SELECTED METABOLIC ASPECTS OF PIKE-PERCH, *STIZOSTEDION LUCIOPERCA* (L.) REARED IN A WATER RECIRCULATION SYSTEM

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**ABSTRACT.** The aim of the present study was to evaluate the effect of fish size ( $BW$  11.7 g in the PS group, and 28.1 g in the PL group), feeding (SDA effect), and starvation (4, 13, 19 or 26 days in the PS-S group, and 4 or 13 days in the PL-S group) on oxygen consumption ( $OC$ ,  $\text{mg O}_2 \text{ kg}^{-1} \text{ h}^{-1}$ ), and ammonia excretion ( $AE$ ,  $\text{mg TAN kg}^{-1} \text{ h}^{-1}$ ) of the juvenile pike-perch *Stizostedion lucioperca* (L.) reared in water recirculation systems. The fish were fed high-protein commercial trout pellets for 18 h  $\text{d}^{-1}$  at daily rates of 2.5% (PS) or 1.2% (PL) of stock biomass. The average  $OC$  and  $AE$  values of the fed pike-perch from the PS group were equal to  $355.70 \text{ mg O}_2 \text{ kg}^{-1} \text{ h}^{-1}$  and  $21.21 \text{ mg TAN kg}^{-1} \text{ h}^{-1}$ , respectively, and were 35% ( $OC$ ) and 62% ( $AE$ ) higher than in the PL group ( $P < 0.05$ ). The metabolic rate of the starved fish was also inversely related to fish size and showed significant differences ( $P < 0.05$ ). The energetic value of SDA was  $62.8 \text{ kJ kg fish}^{-1} \text{ d}^{-1}$  (7.3% of feed digestible energy content) in the PS group, and  $31.6 \text{ kJ kg fish}^{-1} \text{ d}^{-1}$  (5.2% of digestible energy) in the PL group. The starvation period of four days was too short for  $OC$  and  $AE$  stabilization. The values of both parameters stabilized in the second and third week of starvation.

Key words: *STIZOSTEDION LUCIOPERCA*, JUVENILES, OXYGEN CONSUMPTION, AMMONIA EXCRETION, SDA EFFECT, WATER RECIRCULATION SYSTEMS

## INTRODUCTION

The production of fish stocking material in water recirculation systems is advantageous for many reasons including independence from variable atmospheric conditions and the possibility of controlling water quality which is essential for successful fish rearing (Kolman 1992, 1999, Colt and Orwicz 1991). However, this method also has some drawbacks such as water quality deterioration during rearing, including particularly dangerous oxygen depletion and the buildup of toxic metabolites (Westers and Pratt 1977, Fivelstad 1988, Fivelstad et al. 1991). Therefore, using water recirculation systems for fish rearing necessitates water treatment such as oxygen supply and metabolite removal (Kolman 1999). Due to the use of high-protein diets and high stocking densities, the treatments must be very efficient. We are able to calculate the optimum stocking densities if we know the possibilities of water quality improvement, oxygen consumption and the amount of excreted metabolites, mainly nitrogen compounds and carbon dioxide.

Fish metabolic rate depends on various biotic and abiotic factors (Jobling 1981a, 1982, 1994, Zakęś 1999). The most important are fish size (ontogenetic development stage), and feeding. The metabolic cost of food absorption (SDA effect) comprises a large part of the gross energy content of the chosen feed. According to the data of various authors, this usually ranges from 9 to 25% of the digestible energy in the food content (Jobling and Davies 1980, Jobling 1981b, Soofiani and Hawkins 1982). The magnitude of the SDA effect depends on many factors such as fish species, developmental stage, feeding rate and feed composition, and water temperature (Kaushik 1980, Beamish and Trippel 1990, Guinea and Fernandez 1991). The evaluation of the SDA effect requires measurements of metabolic rate, oxygen consumption and/or ammonia excretion of fed and starved fish. Metabolic rate stabilization usually requires quite a long period of starvation, often more than seven days (Kaushik 1980).

Studies carried out thus far on the metabolic rate of the pike-perch, *Stizostedion lucioperca* (L.) juveniles reared in water recirculation systems have addressed the effects of feeding rates, photoperiod, water temperature, the chemical composition of feed, and fish size (Zakes 1998, Zakęś 1999, Zakes and Karpinski 1999). No data are available on the effect of a starvation period on pike-perch metabolic rate. Such a study would allow for the determination of the starvation period necessary for metabolic rate stabilization. This, in turn, would make the evaluation of the effect of fish feeding on oxygen consumption and ammonia excretion possible.

The aim of the present study was to assess the effect of fish size, feeding, and starvation period on the metabolic rate of pike-perch juveniles reared in a water recirculation system, expressed as oxygen consumption and ammonia excretion rates, and their diurnal dynamics.

## MATERIAL AND METHODS

The study was done on pike-perch juveniles obtained from artificial spawning and reared in a water recirculation system. In the first phase of rearing (from day 4 to 21 post-hatch – D4-D21), the fish were fed mixed food (*Artemia* sp. and artificial feed), followed by artificial feed alone. In the next phase (D22-D100), the fish were divided into two experimental groups. In the first part of the experiment 101-day-old fish were used which had an average body mass of  $11.72 \pm 2.73$  g and total length (TL) of  $10.78 \pm 0.86$  cm (small pike-perch – PS). The second group was reared for another 27 days (D128) until they reached  $28.05 \pm 8.80$  g and  $14.34 \pm 1.31$  cm TL (large pike-perch – PL).

## EXPERIMENTAL CONDITIONS

Each experimental group was kept in two independent water recirculation systems. Each of them consisted of three 200 l circulation tanks 71 cm in diameter and 72 cm deep, and each was stocked with 150 pike-perch individuals. The systems were equipped with biological filters filled with PFS 4020 LDPE polyethylene pellets, mechanical filters, and a heater automatically regulated with a type ST 33 MR-electronic microprocessor programmer that maintained the water temperature at a constant level of about 22°C. Inlet dissolved oxygen (DO) concentration was 8 mg l<sup>-1</sup> and total ammonia nitrogen (TAN) did not exceed 0.04 mg l<sup>-1</sup> (Table 1). Flow rates for the PS group ranged from 4 l min<sup>-1</sup> (fed fish) to 1.5 l min<sup>-1</sup> (the last daily sample of starved fish), and for the PL group – from 4 to 2 l min<sup>-1</sup>. The rearing room was illuminated 24 hours a day with a light intensity of approximately 100 lx; at the water surface it was between 40-50 lx.

**TABLE 1**

Water parameters during measurements of juvenile pike-perch metabolic rates [the average values (SD)]

Date (1998)	Water temperature (°C)	pH	Oxygen concentration (mg O <sub>2</sub> l <sup>-1</sup> )		Total ammonia nitrogen concentration TAN (mg TAN l <sup>-1</sup> )	
			inflow	outflow	inflow	outflow
group PS						
13/14.08	21.9 (0.09)	7.59 (0.10)	7.82 (0.05)	5.17 (0.39)	0.036 (0.010)	0.181 (0.050)
18/19.08	22.0 (0.09)	7.62 (0.05)	8.04 (0.02)	6.66 (0.07)	0.008 (0.003)	0.038 (0.012)
27/28.08	21.9 (0.15)	7.64 (0.03)	8.09 (0.02)	6.51 (0.12)	0.011 (0.011)	0.026 (0.013)
03/04.09	21.5 (0.23)	7.72 (0.05)	8.04 (0.02)	6.53 (0.15)	0.011 (0.012)	0.024 (0.010)
10/11.09	22.0 (0.19)	7.52 (0.06)	8.15 (0.03)	5.69 (0.14)	0.013 (0.010)	0.033 (0.010)
group PL						
09/10.09	21.9 (0.12)	7.58 (0.09)	7.74 (0.07)	5.02 (0.49)	0.014 (0.011)	0.110 (0.051)
14/15.09	22.0 (0.18)	7.72 (0.04)	8.02 (0.03)	6.35 (0.07)	0.013 (0.003)	0.022 (0.011)
23/24.09	21.8 (0.20)	7.76 (0.06)	8.09 (0.03)	5.36 (0.19)	0.003 (0.004)	0.013 (0.013)

## EXPERIMENTAL PROCEDURE

The fish were fed high-protein (protein 52%, fat 21%, carbohydrate 10%, gross energetic value 22.3 MJ kg<sup>-1</sup>, digestible energy 19.3 MJ kg<sup>-1</sup>) SUPRA FK trout pellets 1.5 mm in diameter (Felleskjopet, Havbruk, Norway). The feed was supplied 18 hours a day (09.00-03.00) using 4305 FIAP (Fish Technic GMBH) automatic conveyor feeders at rates of 2.5 or 1.2% of stock biomass for the first and second experimental group, respectively.

The day before each metabolic rate measurement, 20 fish were randomly sampled from each tank. The specimens were anaesthetized using  $1.5 \text{ ml l}^{-1}$  of Propiscin (Szkudlarek and Zakęś 1996), then they were weighed ( $BW \pm 0.01 \text{ g}$ ) and measured ( $TL \pm 0.01 \text{ cm}$ ). The fish biomass in each tank was also evaluated by weighing all the fish in a known volume of water.

Diurnal studies of the metabolic rate of the PS fish were carried out from August 13 to September 11, 1998. The first measurement was taken on August 13-14 (small pike-perch, fed – PS-F group) and were followed by measurements after 4, 13, 19, and 26 days of starvation (groups PS-S1, PS-S2, PS-S3, and PS-S4). The measurements of metabolic rate of the second group began on September 9 (PL-F), and continued after 4 and 13 days of starvation (PL-S1, PL-S2).

Water was sampled from the inlet and outlet (300 ml) in diurnal cycles every 60 min. DO and TAN ( $\text{NH}_4^+\text{-N} + \text{NH}_3\text{-N}$ ) levels were measured. DO concentration was measured using a DO-meter from YSI Inc., Yellow Springs, Ohio, USA. Total ammonia nitrogen concentration was evaluated using the salicylate-hypochlorite method (Bower and Holm-Hansen 1980). Water pH was measured with a 1000 pH/T ISFET scale.

Oxygen consumption (*OC*) and ammonia excretion (*AE*) expressed as  $\text{mg O}_2$  or  $\text{mg TAN kg}^{-1}$  of fish  $\text{h}^{-1}$  was calculated from the differences of DO or TAN levels between the inflow ( $\text{DO}_i$  or  $\text{TAN}_i$ ) and outflow ( $\text{DO}_e$  or  $\text{TAN}_e$ ), at a known flow rate (*Q*), and fish biomass (*B*), according to the formula:

$$OC = [\text{DO}_i - \text{DO}_e (\text{mg l}^{-1}) \times Q (\text{l min}^{-1}) \times 60 \text{ min h}^{-1}] / B (\text{kg}), \quad (1)$$

and

$$AE = [\text{TAN}_e - \text{TAN}_i (\text{mg l}^{-1}) \times Q (\text{l min}^{-1}) \times 60 \text{ min h}^{-1}] / B (\text{kg}) \quad (2)$$

The values of the ammonia quotient (*AQ*) were calculated according to the formula:

$$AQ = (32/14) \times AE/OC \quad (3)$$

where:

(32/14) – mg to mole conversion factor for *AE* and *OC* (Kutty 1978),

*AE*, *OC* – as in formulas (1) and (2).

The values of the SDA effect were calculated from the daily oxygen consumption, using the oxycaloric coefficient  $13.59 \text{ kJ g}^{-1}$  of oxygen (Jobling 1994).

The data concerning the pike-perch metabolic rate ( $OC$ ,  $AE$ ,  $AQ$ ,  $N = 2$ ) were analyzed using the Statistica package. One-way ANOVA was applied, and, in the case of significant differences ( $P < 0.05$ ), the Scheffe's test was used.

## RESULTS

### AVERAGE METABOLIC RATE AND FISH SIZE

The average  $OC$  and  $AE$  values of fed small pike-perch (PS-F group, feeding rate 2.5% of the stock biomass) were equal to 355.70 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> and 21.21 mg TAN kg<sup>-1</sup>h<sup>-1</sup>. These values were 35% ( $OC$ ) and 62% ( $AE$ ) higher than in large pike-perch (PL-F, feeding rate 1.2% of the stock biomass). The minimum and maximum daily  $OC$  and  $AE$  values (Table 2) also significantly differed between the groups. The differences in the ammonia quotient ( $AQ$ ) were highly significant ( $P < 0.05$ , Table 2). The calculated  $AQ$  values show that PS-F and PL-F fish used 40.6 and 23.0% of the oxygen, respectively, for protein oxidation.

The metabolic rate of the starved fish was also inversely related to their size and exhibited significant differences. The oxygen consumption in the PS-S group (the average of four  $OC$  values obtained for starved fish) was about 17% higher compared to PL-S (the average of two  $OC$  values for starved fish). The ammonia excretion level was 2.01 mg TAN kg<sup>-1</sup>h<sup>-1</sup> in PS-S, which was 66% higher than in the PL-S group ( $P < 0.05$ , Table 2). Statistical analysis also revealed highly significant differences in average ammonia quotient ( $AQ$ ) values between the PS-S and PL-S groups ( $P < 0.05$ ).

### THE EFFECT OF FEEDING ON METABOLIC RATE

The daily  $OC$  values of fed (PS-F) and starved (PS-S) small pike-perch were 8536.8 and 3917.3 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup>, respectively. Therefore, 4619.5 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> was used for food absorption (the SDA effect). The energetic value of the SDA effect was 62.8 kJ kg of fish<sup>-1</sup>d<sup>-1</sup>, comprising 7.3% of the digestible energy in the feed. Oxygen consumption of the large fed fish (PL-F) was about 42% higher compared to the  $OC$  of the starved fish (PL-S). The SDA value was equal to 31.6 kJ kg of fish<sup>-1</sup>d<sup>-1</sup> and comprised 5.2% of the digestible energy.

The fed fish (PS-F) excreted 509.04 mg TAN kg<sup>-1</sup>d<sup>-1</sup> which was over ten times more than the starved fish (PS-S). A similar difference was observed for the larger-sized groups (PL-F and PL-S) (Table 3). Endogenous ammonia excretion (ENE) comprised about 10% of  $AE$  in both size groups (Table 3).

TABLE 2

Oxygen consumption (OC) and ammonia excretion (AE) rates, and ammonia quotient (AQ) in two size groups of juvenile pike-perch (PS and PL), fed (F) and starved (S)

Group	Metabolic rates			Differences maximum – mean (%)
	mean*	minimum*	maximum*	
	OC (mg O <sub>2</sub> kg <sup>-1</sup> h <sup>-1</sup> )			
group PS-F	355.70 A	260.26 A	411.84 A	115.80
group PL-F	231.55 B	176.58 A	278.49 B	120.30
<i>P</i>	0.0000	0.1469	0.0093	
group PS-S	163.22 A	144.60 A	187.08 A	114.62
group PL-S	134.63 B	122.81 A	144.76 B	110.00
<i>P</i>	0.0000	0.0616	0.0142	
	AE (mg TAN kg <sup>-1</sup> h <sup>-1</sup> )			
group PS-F	21.21 A	10.46 A	26.94 A	127.00
group PL-F	8.13 B	1.75 B	13.11 B	161.20
<i>P</i>	0.0000	0.0162	0.0287	
group PS-S	2.01 A	1.01 A	3.19 A	158.71
group PL-S	0.68 B	0.10 A	1.42 B	210.29
<i>P</i>	0.0000	0.1230	0.0191	
	AQ			
group PS-F	0.134 A	0.086 A	0.162 A	120.70
group PL-F	0.076 B	0.022 B	0.114 A	149.70
<i>P</i>	0.0000	0.0069	0.1210	
group PS-S	0.027 A	0.015 A	0.045 A	166.67
group PL-S	0.011 B	0.001 A	0.023 B	209.10
<i>P</i>	0.0000	0.1089	0.0124	

\* values in column with same letter are not significantly different ( $P > 0.05$ )

## THE EFFECT OF STARVATION TIME ON METABOLIC RATE

The average oxygen consumption in PS-S fish starved from 4 to 26 days decreased from 185.14 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> in PS-S1 to 137.96 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> in PS-S4, showing a significant difference ( $P < 0.05$ , Table 4). After 13 days of starvation, the oxygen consumption rate stabilized at a level of about 160 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup>. A similar reaction was also observed for ammonia excretion. The average ammonia excretion rate decreased from 3.95 mg TAN kg<sup>-1</sup>h<sup>-1</sup> in PS-S1 to 1.12 mg TAN kg<sup>-1</sup>h<sup>-1</sup> in PS-S4. Both OC and AE values of PS pike-perch starved for 26 days were significantly lower than they were after 4, 13, and 19 days of starvation (Table 4).

TABLE 3

The values of specific dynamic action (SDA) for juvenile pike-perch of two size groups (PS and PL)

Group	Feed ration (% BW d <sup>-1</sup> )	Metabolic rate			
		Mean OC or AE mg O <sub>2</sub> or TAN kg <sup>-1</sup> d <sup>-1</sup>	SDA effect		
			mg O <sub>2</sub> or TAN kg <sup>-1</sup> d <sup>-1</sup>	%*	kJ kg fish <sup>-1</sup> d <sup>-1</sup>
<b>OC</b>					
group PS-S	0	3917.3			
group PS-F	2.5	8536.8	4619.5	54.11	62.8
group PL-S	0	3231.1			
group PL-F	1.2	5557.2	2326.1	41.86	31.6
<b>AE</b>					
group PS-S	0	48.24			
group PS-F	2.5	509.04	460.80	90.52	
group PL-S	0	16.32			
group PL-F	1.2	195.12	178.80	91.64	

\* [(the SDA effect in mg O<sub>2</sub> or TAN kg<sup>-1</sup> d<sup>-1</sup>) × 100] / average mg O<sub>2</sub> or TAN kg<sup>-1</sup> d<sup>-1</sup>

The value of the ammonia quotient (AQ) in the PS-S1 group (fish starved for 4 days) was significantly higher compared to that of fish which were starved for a longer time ( $P < 0.05$ , Table 4).

The results obtained for large pike-perch show similar patterns; the average OC value decreased after 13 days of starvation from 146.28 in PL-S1 to 122.98 mg O<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> in PL-S2, and the AE value fell from 0.84 to 0.52 mg TAN kg<sup>-1</sup> h<sup>-1</sup> ( $P < 0.05$ , Table 4).

#### DIURNAL OC AND AE DYNAMICS

In the fed fish (PS-F and PL-F) groups, diurnal patterns of oxygen consumption (OC) and ammonia excretion (AE) were related to feeding patterns. Both OC and AE started to increase about 2-3 hours after feeding had begun (11.00 – 12.00). Over the following 6-8 hours a further considerable increase of OC and AE took place, and both values stabilized. After the end of feeding (03.00), both values gradually decreased to the initial level.

The diurnal OC variability (the difference between the maximum and average OC values) was similar in both size groups of fed pike-perch and equal to 115.8% in PS-F and 120.3% in PL-F. The differences in ammonia excretion were higher and ranged from 127.0% in PS-F to 161.2% in PL-F (Table 2).

TABLE 4

Oxygen consumption (*OC*) and ammonia excretion (*AE*) rates, and ammonia quotient (*AQ*) of smaller (PS-S) and larger (PL-S) starved juvenile pike-perch

Group	Starvation (days)	Metabolic rates			Differences maximum – mean (%)
		mean*	minimum*	maximum*	
<i>OC</i> (mg O <sub>2</sub> kg <sup>-1</sup> h <sup>-1</sup> )					
group PS-S1	4	185.14 A	169.36 A	201.05 A	108.6
group PS-S2	13	165.58 B	144.10 AB	186.97 A	112.9
group PS-S3	19	164.22 B	137.76 B	182.81 A	111.3
group PS-S4	26	137.96 C	127.18 B	151.86 B	110.1
<i>P</i>		0.0000	0.0171	0.0528	
group PL-S1	4	146.28 A	138.76 A	155.71 A	106.4
group PL-S2	13	122.98 B	109.46 B	133.82 A	108.8
<i>P</i>		0.0000	0.0066	0.0675	
<i>AE</i> (mg TAN kg <sup>-1</sup> h <sup>-1</sup> )					
group PS-S1	4	3.95 A	2.93 A	4.86 A	123.0
group PS-S2	13	1.59 B	0.79 B	2.82 B	176.7
group PS-S3	19	1.40 B	0.06 B	2.62 B	187.1
group PS-S4	26	1.12 C	0.14 B	2.19 B	195.4
<i>P</i>		0.0000	0.0024	0.0336	
group PL-S1	4	0.84 A	0.13 A	1.83 A	219.4
group PL-S2	13	0.52 B	0.05 B	1.01 B	196.4
<i>P</i>		0.0005	0.0006	0.0228	
<i>AQ</i>					
group PS-S1	4	0.049 A	0.038 A	0.060 A	123.5
group PS-S2	13	0.022 B	0.011 B	0.038 A	171.4
group PS-S3	19	0.020 B	0.009 B	0.038 A	193.7
group PS-S4	26	0.019 B	0.002 B	0.036 A	194.6
<i>P</i>		0.0000	0.0038	0.1279	
group PL-S1	4	0.013 A	0.002 A	0.028 A	212.9
group PL-S2	13	0.009 B	0.001 B	0.018 B	192.6
<i>P</i>		0.0119	0.0039	0.0320	

\* values in column with same letter are not significantly different ( $P > 0.05$ )

The diurnal *OC* and *AE* dynamics in both groups of starved fish did not show any distinct pattern and were polymodal, with several periods of increase and decrease that varied over the course of each diurnal cycle. The differences between the maximum and average *OC* levels were lower than those in the fed fish. On the other hand, ammonia excretion variability in the starved fish was higher than in the fed fish (Tables 2 and 4).

## DISCUSSION

Oxygen consumption by poikilothermic vertebrates is usually lower than in homoiothermic ones. In both groups, however, the  $OC$  – body mass relationships are linear in logarithmic scales (Schmidt-Nielsen 1997). The metabolic rate per body mass unit decreases with an increase in body size in all animals, including fish. In fish, this can be explained by the changes of the relative size of various organs during growth. In ontogenetic development, the relative mass of highly active organs such as the liver or the digestive tract decreases. It has also been suggested that the metabolic activity of various fish tissues declines (Jobling 1994). The effect of body size on metabolic rate in fish has been studied extensively (Jobling 1981a, 1994, Cai and Summerfelt 1992, Yager and Summerfelt 1993). In an earlier study done at the same water temperature (22°C), the average oxygen consumption and ammonia excretion in *S. lucioperca*, with an average body weight ranging from 1.6 to 38.1 g, decreased from 701.4 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> and 38.67 mg TAN kg<sup>-1</sup>h<sup>-1</sup> to 243 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> and 11.94 mg TAN kg<sup>-1</sup>h<sup>-1</sup>, respectively. The relationships between  $OC$  or  $AE$  rates and body weight ( $BW$ ) were expressed using the following equations:  $OC = 831.97 BW^{-0.3512}$ ;  $AE = 46.41 BW^{-0.3682}$  (Zakes 1998). In the present study, the  $OC$  and  $AE$  rates evaluated for *S. lucioperca* with an average body mass of 11.7 and 28.1 g (within the range reported in the previous study) were 355.70 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> and 21.21 mg TAN kg<sup>-1</sup>h<sup>-1</sup> in the PS-F group, and 231.55 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> and 8.13 mg TAN kg<sup>-1</sup>h<sup>-1</sup> in the PL-F group. The  $OC$  values calculated for both fish size groups according to the previously developed formulas were very similar – 350.72 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> (for PS-F,  $BW$  11.7 g), and 257.98 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> (for PL-F,  $BW$  28.1 g). Larger differences between observed and calculated values were found for the ammonia excretion rates. The values calculated according to the equation were 18.76 mg TAN kg<sup>-1</sup>h<sup>-1</sup> (for PS-F,  $BW$  11.7 g) and 13.59 mg TAN kg<sup>-1</sup>h<sup>-1</sup> (for PL-F,  $BW$  28.1 g). These differences might have resulted from different feeding patterns in the current and previous experiments (Zakes 1998). It is obvious that ammonia production is closely related to the feeding rate (Beamish and Thomas 1984, Fivelstad 1988, Li and Lovell 1992). Therefore, the formula which describes the  $AE$  -  $BW$  relationship for certain water temperatures should also take into account the feeding rate. The size of the smaller fish ( $BW$  11.7 g) was similar (10.6-10.8 g) to that used in an experiment on the effect of water temperature (20 and 24°C) on the metabolic rate of pike-perch (Zakes and Karpinski 1999). The average

OC and AE values obtained for fish kept at the higher temperature were 356.2 mg O<sub>2</sub> kg<sup>-1</sup>h<sup>-1</sup> and 18.3 mg TAN kg<sup>-1</sup>h<sup>-1</sup>, and were very similar to those of the PS-F fish in the present experiment. The rate of metabolic processes within a narrow thermal range may be temperature-independent (Jobling 1994). Such ranges are usually found within the optimum limits for these processes. Therefore, the results indicate that 22-24°C is an optimum range for pike-perch with a body weight slightly above 10 g which are fed an artificial diet.

The metabolic rate of fish increases significantly as a result of feeding. Specific dynamic action (SDA effect) includes three main indices: maximum value, duration, and absolute value. The latter may be established if the exact duration of the SDA effect is known, in other words, the period during which the metabolic rate of starved fish stabilizes must be known. The duration of the SDA effect depends on many factors such as species (Muir and Niimi 1972), body size (developmental stage) (Beamish 1974), feed consumption (Beamish 1974, Jobling and Davies 1980, Jobling 1994), and water temperature (Beamish and Trippel 1990, Jobling 1994). However, such relationships are not always observed, e.g. LeGrow and Beamish (1986) and Guinea and Fernandez (1997) did not find that the feeding rate affected the duration of the SDA effect. According to Guinea and Fernandez (1997), the duration of the SDA effect for cod, *Gadus morhua* L. juveniles fed an artificial diet at a rate of 1 or 2% BW did not differ, and was about 37-39 hours. Saunders (1963) reported that the SDA effect in the alholehole, *Kuhlia sandvicensis* lasted about seven days, whereas Kaushik (1980) observed that the rates of nitrogen metabolite excretion in the common carp, *Cyprinus carpio* L. and the rainbow trout, *Oncorhynchus mykiss* (Walbaum) did not stabilize even after seven days of starvation. According to Jobling (1994), reliable values of the standard metabolic rate in fish can usually be obtained after two to three days, but, in some cases, this period may be too short since the duration of the SDA effect depends on various factors. The results of the present study indicate that for *S. lucioperca* reared at 22°C, a starvation period of two to three days is too short. The average OC and AE values after four days of starvation were significantly higher than those obtained after a longer time (13, 19, and 26 days). Also, the average AQ values were significantly higher after four days of starvation than later ( $P = 0.0000$ , Table 4). These data suggest that a portion of the ammonia excreted by the fish after four days of starvation was of exogenous origin and resulted from the deamination of amino acids in the feed. The results indicate that OC and AE values stabilized after the fish had been starved for longer than a week, and that they remained constant for the next two

weeks. Further starvation resulted in a reduction of *OC* and *AE* which can be explained by changes in the biochemical composition of fish tissues and in the relative size of various organs. A reduction in ribosome numbers, protein synthesis rate, and metabolic activity are observed in animals that are starved for a long period (Love 1970, Jobling 1994). The metabolic rate reduction observed in small pike-perch starved for 26 days might have resulted from such changes.

For most fish species, the SDA effect comprises a considerable portion of the energy obtained from feed. For the bluegill, *Lepomis macrochirus* feed utilization costs range from 4.8 to 24.4% of the energetic value of the feed (Pierce and Wissing 1974). According to Vahl and Davenport (1979), the SDA in blenny, *Blennius pholis* L. comprises 10% of the digestible energy from feed. Juvenile coho salmon, *Oncorhynchus kisutch* exhibited an SDA ranging from 3.4 to 45% of the digestible energy (most values fell within the range of 9-15%) at various water temperatures and feeding rates (Averett 1969, cited in Soofiani and Hawkins 1982). The values observed for *S. lucioperca* in the present study were near the lower limit of those reported by other authors – 5.2-7.3% of the digestible energy. For juvenile *S. lucioperca* reared at various water temperatures, the SDA ranged from 7.1 to 10.8% of the digestible energy (Zakęs 1999). It seems, however, that these values may be underestimated because the SDA values were calculated from the difference of daily oxygen consumption by the fed and starved fish (after 14 days of starvation). The present study revealed that the effect of consumed feed on the metabolic rate of *S. lucioperca* can be observed for longer than a week into the starvation period. Therefore, more reliable SDA effect values could be obtained from direct measurements of metabolic rate changes over this period. We should, however, remember that long-term starvation causes stress in fish and enhances aggressive behavior in predatory species. Under such conditions, the energy expended on active metabolism increases, and this may affect the results.

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## STRESZCZENIE

### WYBRANE ASPEKTY METABOLIZMU SANDACZA, *STIZOSTEDION LUCIOPERCA* (L.), PODCHOWANEGO W ZAMKNIĘTYM OBIEGU WODY

Celem badań było określenie wpływu wielkości ryb (BW 11,7 g – grupa PS i 28,1 g – grupa PL), żywienia (efekt SDA) i czasu głodzenia (4, 13, 19 i 26 dni – grupa PS-S i 4, 13 dni – grupa PL-S) na wielkość zapotrzebowania tlenowego (OC, mg O<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>) i wydalania amoniaku (AE, mg TAN kg<sup>-1</sup> h<sup>-1</sup>) przez juwenalnego sandacza, *Stizostedion lucioperca* (L.) podchowowanego w zamkniętym obiegu wody. Ryby karmiono przez 18 h d<sup>-1</sup> wysokobiałkowym, komercyjnym granulatem pstragowym. Dobowa dawka paszy wynosiła 2,5% (grupa PS) i 1,2% biomasy obsad (grupa PL). Średnie wartości OC i AE sandacza żywionego z grupy PS wynosiły odpowiednio: 355,70 mg O<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> oraz 21,21 mg TAN kg<sup>-1</sup> h<sup>-1</sup> i były o 35% (OC) i 62% (AE) wyższe od obliczonych dla drugiej grupy wielkości (grupa PL;  $P < 0,05$ ). Tempo metabolizmu ryb głodzonych było także odwrotnie proporcjonalne do wielkości ryb, a różnice międzygrupowe były istotne statystycznie ( $P < 0,05$ ).

Energetyczna wartość efektu SDA wyniosła 62,8 kJ kg ryb<sup>-1</sup> d<sup>-1</sup>, co stanowiło 7,3% energii strawnej zawartej w pobranej paszy (grupa PS) oraz 31,6 kJ kg ryb<sup>-1</sup> d<sup>-1</sup>, czyli 5,2% energii strawnej (grupa PL). Ryby karmione (grupa PS-F) wydalaly 509,04 mg TAN kg<sup>-1</sup> d<sup>-1</sup>, czyli ponad dziesięciokrotnie więcej niż ryby głodzone (grupa PS-S). Podobne dysproporcje w wielkości produkcji amoniaku dotyczyły ryb z drugiej grupy wielkości (grupy PL-F i PL-S). Poziom wydalania endogenne amoniaku (ENE) w obydwu grupach wielkości stanowił około 10% całkowitego amoniaku wydalanego przez ryby.

Okres czterech dni głodzenia ryb, z obydwu grup wielkości, był zbyt krótki do ustabilizowania się wielkości OC i AE. Parametry te osiągały stabilną wartość w drugim i trzecim tygodniu głodzenia ryb.

W grupach ryb żywionych (grupy PS-F i PL-F) przebieg dobowych profilów konsumpcji tlenu (OC) i wydalania amoniaku (AE) był ściśle związany z karmieniem ryb. Przebieg dobowych profilów OC i AE obserwowany w obu grupach wielkości ryb głodzonych nie wykazywał jakichkolwiek tendencji i prawidłowości.

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