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OXYGEN CONSUMPTION AND AMMONIA EXCRETION BY JUVENILE PIKE, *ESOX LUCIUS* L.

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ABSTRACT. The aim of the study was to determine the level of oxygen consumption (OC; mg O_2 kg^{-1} h^{-1}) and ammonia excretion (AE, mg TAN kg^{-1} h^{-1}; (TAN = NH_4^+-N + NH_3-N)) by juvenile pike, *Esox lucius* L. reared in recirculating systems at two water temperatures (20 and 24°C). The quantity of oxygen necessary to metabolize 1 kg of feed (OFR, kg O_2 kg^{-1} feed day^{-1}) and the quantitiy of ammonia excreted after the metabolism of this same quantity of feed (AFR, kg TAN kg^{-1} feed day^{-1}) were both determined. During a routine six-week period of rearing fish on commercial feed, 24-hour measurements of OC and AE were taken three times. The mean pike body weight during subsequent measurements was 68 g (group I), 80 g (group II), and 90 g (group III). The oxygen consumption of fish held at 24°C was higher than that of fish reared at 20°C; however, only with regard to the fish with the lowest body weight (group I) was the intergroup difference statistically significant ($P < 0.05$). It was confirmed that the pike oxygen consumption at both 20 and 24°C decreased along with increasing body weight, and the intragroup differences were statistically significant ($P < 0.05$). Inceases in body weight of 1 g in the fish reared at 20 or 24°C caused decreases in OC of 2.36 and 2.78 mg O_2 kg^{-1} h^{-1}. Water temperature did not have a statistically significant impact on the values of AE determined during the three pike metabolism measurement cycles. Body weight had a more significant impact on the ammonia excretion rate ($P < 0.05$). Water temperature was not noted to have a significant impact on the values of OFR and AFR. It was confirmed, however, that body weight had a significant impact on the values of these parameters; OFR and AFR values deceased as the fish grew ($P < 0.05$).

Key words: PIKE (*ESOX LUCIUS*), OXYGEN CONSUMPTION, AMMONIA EXCRETION, WATER TEMPERATURE, RECIRCULATING SYSTEMS

INTRODUCTION

In many European countries the pike, *Esox lucius* L., is a valuable fish species both commercially and ecologically. It is also particularly popular among anglers (Paukert et al. 2001, Armand et al. 2002). The decline in pike abundance noted in recent years is attributed to

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strong anthropogenic pressure and disadvantageous environmental changes related to, among other factors, the degradation of the littoral zones of aquatic basins, which are the natural spawning grounds and habitat of this species (Casselman and Lewis 1996, Balik et al. 2006). In concequence, measures are being taken to preserve this species. These include closed fishing seasons, legal size limits, daily catch limits, protected spawning grounds, as well as the intensified stocking of natural basins (Paukert et al. 2001).

To date, natural waters have been stocked with pike larvae produced in hatcheries or with older material obtained from extensive pond production (e.g., Mickiewicz 2006). With the goal of intensifying the production of pike stocking material, studies have been undertaken to verify the possibilities of rearing such material in ponds (Žiliukiene and Žiliukas 2006) and in closed recirulating systems (e.g., Wolnicki and Górny 1997). Studies of rearing larvae on formulated feed under controlled conditions were initiated as ealy as the 1970s (Timmermans 1979, Westers 1979). Although there were no significant problems during the intial rearing of larvae (first 10-20 days), problems were encountered once the fish attained a body weight of approximately 100-200 mg as this was when cannibalism became more prevalent (Wolnicki and Kamiński 1998). Recent studies have indicated, however, that appropriate technical conditions during rearing and proper feeding can contribute to the largely successful rearing of juvenile pike (Kucska et al. 2005, Szczepkowski 2006, Szczepkowski, unpublished data). Initial research also indicated that using this type of material to stock natural basins increases the effectiveness of this procedure (Szczepkowski et al. 2006).

It was confirmed that water temperature is a highly significant factor that determines the effectiveness of intense rearing (e.g., growth rate, survival, feed conversion efficiency) of both larvae and juvenile pike stages in recirculating systems (Górny 1991, Wolnicki and Górny 1997, Szczepkowski 2006). It is worth emphasizing that among the many environmental factors, it is indeed water temperature that has a significant impact on fish oxygen consumption and ammonia excretion (e.g., Cai and Summerfelt 1992, Zakęś et al. 2003). Considering that the concentrations of oxygen and ammonia are the primary limiting factors in the production of fish in recirculating systems, knowledge of the dependence between water temperature and metabolic rate is highly significant (e.g., Colt and Orwicz 1991).

The aim of the experiment presented herein was to determine the levels of oxygen consumption and ammonia excretion of juvenile pike (body weight from 68 to 90 g) reared in recirculating systems at two water temperatures (20 and 24°C).

MATERIALS AND METHODS

FISH AND REARING CONDITIONS

The experimental material were juvenile pike that had been reared at the Dgał Experimental Hatchery in Pieczarki, Inland Fisheries Institute in Olsztyn (IFI Olsztyn; northern Poland). It was derived from the artificial spawning of spawners caught in Lake Dgał Wielki (northern Pland). This material was then reared initially in recirculating systems and fed formulated feed exclusively (Szczepkowski 2006). After the fish had reached a mean body weight of approximately 50 g, 240 individuals were transported to the Department of Aquaculture, IFI Olsztyn. During transport the fish were held in polyethylene bags (20 l water + 20 l oxygen, transport time 2 h). The fish were stocked into six experimental tanks (40 fish tank^{-1}) with a volume of 200 l each (diameter 71 cm, depth 72 cm), that were part of two independent recirculating systems. The systems were fitted with a water purification system comprised of mechanical filters and a biological layer. The substrate for the biological layer was PFS 4020 LDPE polyethylene granules (Petrochemia Płock, Poland). The water temperature in both systems was stabilized (± 0.2°C) with an ST 33 microprocessor thermoregulator (MR-elektronika, Warsaw, Poland). At the moment the fish were stocked into the rearing tanks the water temperature in both recirculation systems was 22°C. After two days the temperature in one of the systems began to be raised to 24°C, while in the second it began to be lowered to 20°C. The changes in temperature were implemented over the course of eight days at a rate of 0.25°C d^{-1}. Following a ten-day adaptation period, the experiment proper began. During the rearing period of six weeks, three 24-hour measurements of pike metabolism were conducted (at intervals of 21 days). The oxygen content at the water inflow and outflow did not fall below 7.60 and 5.57 mg O_2 l^{-1}, respectively, while the concentration of total ammonia nitrogen (TAN = NH_4^+-N + NH_3-N) at the two water temperature variants did not exceed 0.2 mg TAN l^{-1} (Table 1). Water pH throughout the rearing period ranged from 7.84 to 8.39. Water flow was maintained at 3 l min^{-1}, which permitted a water exchange frequency of 0.9 exchange h^{-1}. This also permitted reducing the oxygen concentration between the inflowing and outflowing water to more than 2 mg l^{-1}. During rearing, a 24-hour photoperiod of 24L:0D was applied (light intensity at the water surface of the rearing tanks ranged from 120-150 lx).

TABLE 1

Fish size, stock biomass, feed ration, and physical and chemical water parameters during the experiment (mean values (SD) or range)

	Group I		Group II		Group III	
Parameter	20°C	24°C	20°C	24°C	20°C	24°C
Fish and feeding						
Body weight (g)	69.2 (1.0)	66.4 (0.8)	81.4 (0.7)	78.7 (2.3)	91.2 (0.3)	89.4 (0.6)
Total length (cm)	22.1 (0.04)	21.9 (0.02)	23.2 (0.03)	23.1 (0.14)	24.1 (0.02)	24.1 (0.22)
Stock biomass (kg m^{-3})	14.0	13.3	16.5	15.7	18.5	17.9
Fish loading (kg fish l^{-1} min^{-1})	0.93	0.88	1.10	1.07	1.22	1.21
Feed ration (% stock biomass)	1.3	1.5	1.1	1.3	1.0	1.2
Water inflow						
Temperature (°C)	20.0 (0.1)	23.9 (0.1)	20.1 (0.1)	24.0 (0.0)	20.2 (0.1)	24.1 (0.1)
Oxygen (mg O_2 l^{-1})	9.64 (0.10)	9.42 (0.08)	8.67 (0.11)	7.78 (0.19)	8.36 (0.18)	7.60 (0.14)
Ammonia (mg TAN l^{-1})	0.086 (0.007)	0.080 (0.005)	0.075 (0.002)	0.078 (0.006)	0.078 (0.004)	0.074 (0.003)
Water outflow						
Temperature (°C)	20.0 (0.1)	23.8 (0.0)	20.0 (0.0)	24.0 (0.1)	20.1 (0.1)	24.0 (0.0)
Oxygen (mg O_2 l^{-1})	7.39 (0.11)	6.96 (0.18)	6.48 (0.08)	5.57 (0.12)	6.46 (0.11)	5.64 (0.24)
Ammonia (mg TAN l^{-1})	0.175 (0.016)	0.181 (0.001)	0.114 (0.007)	0.146 (0.014)	0.111 (0.004)	0.108 (0.004)
pH	7.84- 8.10	8.25-8.39	7.90-8.06	8.08-8.16	7.94-8.14	8.03-8.18

FEED AND FEEDING

The fish were fed Trouvit Classic 3 (Trouvit, France) commercial feed with granule size from 3.8-4.3 mm and the following chemical composition: protein 46.0%, fat 14.0%, carbohydrates 21.5%, ash 9.0%, digestable energy 17.0 MJ kg^{-1}. Feed was delivered 19 hours per day (09:00 – 04:00) by an automatic band feeder (4035 FIAP, Fish Technic GmbH, Germany). The daily feed ration ranged from 1.0 to 1.5% of the stock biomass (Table 1).

EXPERIMENTAL PROCEDURE

During rearing and in each temperature variants (20 and 24°C) three 24-hour measurements of oxygen consumption (OC, in mg O_2 kg^{-1} h^{-1}) and total ammonia nitrogen (AE, in mg TAN kg^{-1} h^{-1}) were performed on days 1, 21, and 42 of rearing. The mean pike body weight during the three subsequent 24-hour measurements of OC and AE ranged from 66.4 g (group I) to 91.2 g (group III; Table 1). An oxygen meter (YSI – 58, YSI 5905 BOD Probe (± 0.05 mg O_2 l^{-1}), Yellow Springs Instruments, USA) was used to measure oxygen concentration (mg O_2 l^{-1}) at the inflow and outflow of the rearing tanks. The total ammonia nitrogen (mg TAN l^{-1}) concentration at the inflow and outflow was measured every 2 hours. The determinations were performed with the salicylate-hypochlorite method using a spectrophotometer (wavelength 652 nm) to the nearest ± 0.01 mg TAN l^{-1} (Bower and Holm-Hansen 1980). Measurements of water pH (with a 1000 pH/T ISFET pH-meter) and temperature (± 0.1°C) were also performed.

The mesurement procedure for OC and AE, the calculations used (formulae), and the statistical analyses were analogous to previous studies (Zakęś et al. 2003, 2006). The rates of oxygen consumption (OC) and ammonia excretion (AE) were calculated taking into consideration either the concentrations of oxygen (mg O_2 l^{-1}) or ammonia (mg TAN l^{-1}) between the water flowing into and out of the tanks in which the fish had been stocked, the water flow rate (l min^{-1}), and the biomass of the fish (kg). Water samples were collected from each of the three rearing tanks (n = 3). The quantity of oxygen required to metabolize 1 kg of feed (OFR, kg O_2 kg^{-1} feed day^{-1}) and the quantity of ammonia produced after this amount of feed was metabolized (AFR, kg TAN kg^{-1} feed day^{-1}) was also estimated (Zakęś et al. 2003).

The day following the measurements of OC and AE, the fish in each tank were weighed (BW ± 0.1 g) and measured (TL ± 0.1 cm) individually. Based on the measurements of body size, the biomass of the stock in each of the tanks was estimated. All manipulation was performed on fish that had been anesthetized in a solution of Propiscin (0.75 ml l^{-1} water) (IFI Olsztyn, Kazuń and Siwicki 2001).

RESULTS

OXYGEN CONSUMPTION AND AMMONIA EXCRETION

The oxygen consumption of pike reared at 24°C was higher than that of fish reared at 20°C. However, only in the case of the smallest fish (group I) were the differences among the groups statistically significant ($P < 0.05$; Table 2).

TABLE 2

Oxygen consumption (mg O_2 kg^{-1} h^{-1}) and ammonia excretion (mg TAN kg^{-1} h^{-1}) by juvenile pike in three size groups reared at two water temperatures (mean values (SD))

Size Group BW (g) (no. of reps.)	Mean		Maximum		Minimum		Maximum/ Mean		Maximum/ Minimum	
	20°C	24°C	20°C	24°C	20°C	24°C	20°C	24°C	20°C	24°C
Oxygen consumption										
Group I – *ca* 68 (n=3)	144.79_c^A	166.81_c^B	159.04_c^A	189.41_c^B	122.73_b^A	138.61_b^B	1.10	1.14	1.30	1.37
	(0.19)	(0.54)	(0.91)	(5.93)	(0.35)	(0.19)				
Group II – *ca* 80 (n=3)	119.57_b^A	126.27_b^A	133.50_b^A	147.61_b^A	122.51_b^A	103.10_a^A	1.12	1.17	1.09	1.43
	(2.04)	(3.43)	(3.86)	(9.81)	(9.40)	(4.65)				
Group III – *ca* 90 (n=3)	92.90_a^A	102.79_a^A	108.97_a^A	115.39_a^A	83.35_a^A	93.13_a^A	1.17	1.12	1.31	1.24
	(1.98)	(5.56)	(6.70)	(1.91)	(2.55)	(5.05)				
P	0.0002	0.0010	0.0036	0.0037	0.0403	0.0029				
Ammonia excretion										
Group I – ca 68 (n=3)	5.73_b^A	6.86_c^A	7.97_b^A	12.58_b^A	3.65_b^A	2.96_a^A	1.39	1.83	2.18	4.25
	(1.04)	(0.00)	(2.25)	(2.52)	(1.13)	(1.20)				
Group II – *ca* 80 (n=3)	3.57_{ab}^A	3.93_b^A	5.21_{ab}^A	6.27_a^A	1.85_{ab}^A	1.94_a^A	1.46	1.59	2.82	3.23
	(0.04)	(0.69)	(0.21)	(1.06)	(0.71)	(0.17)				
Group III – *ca* 90 (n=3)	1.59_a^A	1.73_a^A	2.09_a^A	3.65_a^A	0.97_a^A	0.91_a^A	1.31	2.11	2.15	4.01
	(0.02)	(0.20)	(0.03)	(1.07)	(0.01)	(0.20)				
P	0.0143	0.0026	0.0459	0.0218	0.0408	0.1376				

Values marked with the same lowercase subscript letter index in the same column did not differ significantly statistically ($P > 0.05$); values marked with the same uppercase superscript letter index in the same row (for the mean, maximum, and minimum values of the parameters analyzed, respectively) do not differ significantly statistically ($P > 0.05$)

This refers to the minimum, mean, and maximum values of OC recorded during the 24-hour fish metabolism measurement cycles. It was confirmed, however, that the oxygen consumption of pike at both 20 and 24°C decreased as the fish grew. Differences between groups were statistically significant ($P < 0.05$; Table 2). Within the studied fish size, at 20°C the mean OC value decreased from 144.79 to 92.90 mg O_2 kg^{-1} h^{-1} (BW 69.2-91.2 g), and at 24°C from 166.81 to 102.79 mg O_2 kg^{-1} h^{-1} (BW 66.4-89.4 g;

Tables 1 and 2). An increase in weight of 1 g in fish reared at 20 or 24°C resulted in reduced OC by 2.36 and 2.78 mg O_2 kg^{-1} h^{-1}, respectively.

Water temperature did not have a significant impact on the minimum, mean, or maximum values of AE confirmed in the three pike metabolism measurement cycles (Table 2). Fish size (body weight) was found to have a more significant impact on the rate of ammonia excretion of juvenile pike. The mean AE values of fish reared at temperatures of 20 and 24°C were from 5.73 mg TAN kg^{-1} h^{-1} (BW 69.2 g) to 1.59 mg TAN kg^{-1} h^{-1} (BW 91.2 g) and from 6.86 mg TAN kg^{-1} h^{-1} (BW 66.4 g) to 1.73 mg TAN kg^{-1} h^{-1} (BW 89.4 g; Tables 1 and 2). Within the fish sizes studied, increases of body weight of 1 g led to decreases in the mean value of AE by 0.19 mg TAN kg^{-1} h^{-1} (20°C) and 0.22 mg TAN kg^{-1} h^{-1} (24°C).

OFR AND AFR

Water temperature was not noted to have had a statistically signifcant impact on the values of OFR or AFR. This refers to both OFR and AFR calculated with the mean daily values of OC and AE as well as the maximum values (Table 3). Fish body weight was noted, however, to have a significant impact on the level of OFR and AFR; values of these parameters decreased as the fish grew ($P < 0.05$).

DAILY FLUCTUATIONS IN OXYGEN CONCENTRATION AND AMMONIA EXCRETION

The course of the daily OC and AE profiles of fish held at 20 and 24°C was similar. It was noted, however, that they were fairly typical for the individual fish size groups (Fig. 1). A more significant relationship between fish feeding and oxygen consumption and ammonia excretion was confirmed in the first two 24-hour fish metabolic rate measurement cycles (Figs. 1a, b). Nonetheless, increases in OC and AE in the individual 24-hour cycles occurred from 1 to 3 hours after feeding had begun. Relatively high values of these parameters were noted during feeding and from one to two hours after feed delivery had stopped. After this, a dynamic decrease in OC and AE was noted.

There was less variation in OC and AE in a daily cycle at 20°C than there was at the higher temperature investigated. In the case of OC, only in the third fish size group was the reverse tendency oberved (Table 2). It should be emphasized that the impact of temperature on the daily fluctuation of AE was more pronounced than that of OC. This is

TABLE 3

OFR (kg O_2 kg^{-1} feed day^{-1}) and AFR (kg TAN kg^{-1} feed day^{-1}) for juvenile pike reared at 20 and 24°C (mean values (SD))

Size group BW (g) (no. of reps.)	Water temperature (°C) 20	24	20	24
	OFR_{avg}*		OFR_{max}**	
Group I – *ca* 68	0.104_b^A	0.106_c^A	0.114_a^A	0.121_c^A
(n = 3)	(0.001)	(0.001)	(0.001)	(0.004)
Group II – *ca* 80	0.094_{ab}^A	0.085_b^A	0.112_a^A	0.100_b^A
(n = 3)	(0.004)	(0.001)	(0.010)	(0.002)
Group III – *ca* 90	0.087_a^A	0.072_a^A	0.102_a^A	0.081_a^A
(n = 3)	(0.005)	(0.003)	(0.011)	(0.000)
	AFR_{avg}*		AFR_{max}**	
Group I – *ca* 68	0.0041_b^A	0.0043_c^A	0.0057_b^A	0.0080_b^A
(n = 3)	(0.0007)	(0.0000)	(0.0016)	(0.0019)
Group II – *ca* 80	0.0030_{ab}^A	0.0026_b^A	0.0044_{ab}^A	0.0042_{ab}^A
(n = 3)	(0.0001)	(0.0003)	(0.0005)	(0.0005)
Group III – *ca* 90	0.0015_a^A	0.0012_a^A	0.0019_a^A	0.0026_a^A
(n = 3)	(0.0001)	(0.0001)	(0.0001)	(0.0008)

*OFR_{avg} and AFR_{avg} values were calculated from mean daily OC and AE values; ** OFR_{max} and AFR_{max} were calculated from maximum daily OC and AE values; values marked with the same lowercase subscript letter index in the same column did not differ significantly statistically (P > 0.05); values marked with the same uppercase superscript letter index in the same row (for the mean, and maximum values of the parameters analyzed, respectively) do not differ significantly statistically (P > 0.05)*

indicated by the quotient of maximum and mean values, as well as the maximum and minimum values of AE and OC confirmed in the subsequent 24-hour measurement cycle (Table 2).

DISCUSSION

Water temperature is one of the more significant environmental factors impacting the oxygen consumption of fish (e.g., Jobling 1982, 1994). There is a systematic increase in OC along with rises in temperature within the range tolerated by a given species. This dependency is also demonstrated by the results of the current study. It must be emphasized that in the current study intergroup (20 vs 24°C) differences were only statistically different in the pike of the lowest mean BW. With the remaining two

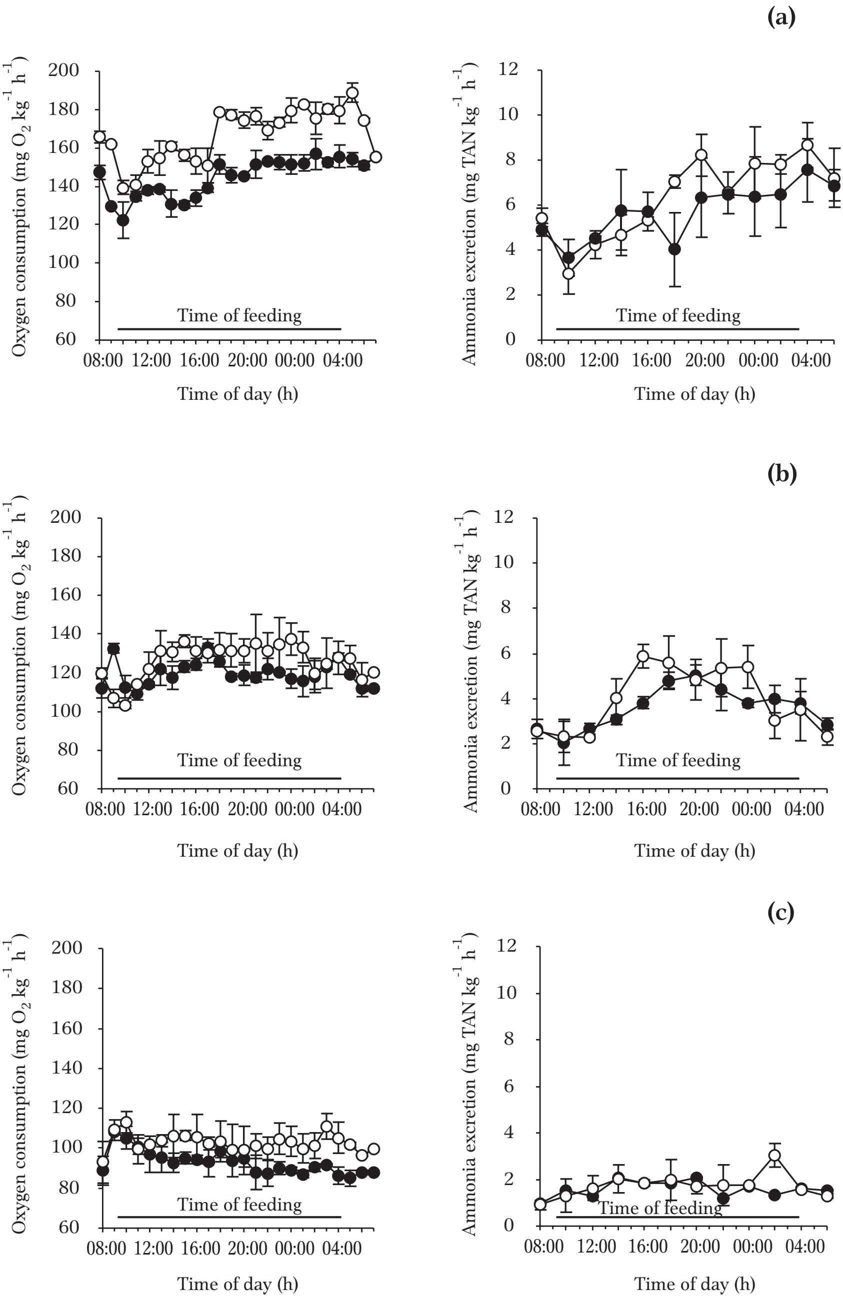

Fig. 1. Diurnal variability of oxygen consumption and ammonia excretion (mean values ±SD) of juvenile pike (a – group I (body weight *ca* 70 g), b – group II (*ca* 80 g), c – group III (*ca* 90 g)) reared at temperatures 20°C (●) and 24°C (○).

fish size groups, the differences were not as significant. However, in comparison with the individuals reared at 20°C those held at the higher temperature (24°C) consumed more oxygen. The metabolic rate of smaller, younger individuals is faster than that of larger, older individuals, and changes in environmental factors (e.g., temperature) can modify it significantly (Schmidt-Nielsen 1994). This might be why only in the case of smaller pike was the OC significant within the studied temperature range. Consideration should also be given to the fact that the impact of water temperature on metabolic rate depends on the studied range of this parameter. It was confirmed that within a narrow temperature range, which is usually within the middle of the range tolerated by a given species, it might be independent of temperature (Jobling 1994). It should also be borne in mind that the OC and AE measurements were conducted on fish that were fed and active under conditions that approximated production levels. This means that the results refer to so-called routine metabolism. Under such conditions, the metabolic rate is determined mainly by feeding and digestion, which can mask the impact of other environmental factors. This regards especially the ammonia excretion rate, which is primarily determined by the quantity and quality (protein content) of the feed consumed (Kaushik 1980, Forsberg 1996). In the current study the excretion of ammonia by fish held at a higher temperature (24 vs 20°C) was higher, but the differences were not statistically significant. It could have been that the feeding intensity of the fish during the AE mesurements masked the impact of water temperature on the quantity of ammonia excretion. It must be emphasized that in studies of other predatory fish juvenile stages (e.g., pikeperch, *Sander lucioperca* (L.) (Zakęś and Karpiński 1999), perch, *Perca fluviatilis* L. (Zakęś et al. 2003)) conducted under similar or identical rearing conditions lower water temperature was noted to have a significant impact on the ammonia excretion rate. From the comparison of the magnitude of OC and AE obtained for the three species under very close rearing conditions (water temperature, feeding schedule, fish size) it can be assumed that pike exhibits significantly lower values of these indicators. For the sake of comparison, the oxygen consumption of juvenile perch (BW ca 80 g, water temperature 23°C) was nearly two fold higher than pike of a similar size (185 vs 100 mg O_2 kg^{-1} h^{-1}). The differences in the ammonia excretion rate between the two species were even greater (5.6 vs 1.7 mg TAN kg^{-1} h^{-1}) (Zakęś and Demska-Zakęś 2005, current study). The OC and AE values for pikeperch were decidedly higher than those for pike (Zakęś 1999). It appears that the difference observed between pike and the other percid species mentioned above might be partially explained by the diverse behavior of these species. Pike is a so-called stationary predator that typically expends little effort to obtain food and has the ability to generate great accelleration when attacking prey (Weihs 1973, Webb 1988). As a result, the energy this species expends on catching or taking food might be significantly lower than the other percid fish with different locomotion kinematics.

The levels of OC and AE determine directly the value of the OFR and AFR indexes. In this regard, the pike indicator values were significantly lower than those for pikeperch or perch (Zakęś 1999, Zakęś and Demska-Zakęś 2005, current study). The preceding observations may have particular practical implications for the intense production of this species, especially in recirculating systems. They indicate that it is possible to rear a greater biomass of fish of this species with a similar amount of so-called available oxygen. Confirmation of this hypothesis would require conducting further studies, for example, to analyze the impact stock density has on the pike metabolic rate.

The current study also indicated that daily variation in OC and AE values is high, which is primarily connected to fish feeding. Due to this, OFR and AFR should be calculated based on the maximum daily values of OC and AE in order to determine the maximum system load. Westers (1981) suggests that with salmonid fish, OFR calculated based on mean OC should be corrected by a factor of 1.44. The results obtained in the current study indicate that a factor of 1.2 (the quotient of maximum and mean OC ranged from 1.10-1.17) would be sufficient for juvenile pike. It should be kept in mind, however, that the magnitude in daily fluctuations of OC and AE are largely dependent on feeding frequency, and that the feeding schedule applied in the current experiment (continuous feeding for 19 hours) lends to the stabilization of these parameters (e.g., Yager and Summerfelt 1994, Zakęś 1999).

The data presented in this paper are but a fragment of information regarding the metabolism of pike reared in closed recirculating systems under conditions similar to those in production. The metabolic rate of pike is significantly lower than that of other predatory species under intense production in aquaculture; this indicates that it would be advantageous to learn more about this species. The current study indicated that the size of the fish (body weight) had a significant impact on the oxygen consumption and ammonia excretion rates, and this suggests that it is especially important to conduct studies to collect comprehensive information about the metabolic rate of pike in various stages of ontogenic development.

REFERENCES

Armand C., Bonnieux F., Changeux T. 2002 – Évaluation économique des plans de gestion piscicole – Bull. Fr. Peche Piscic. 365/366: 565-578.

Balik I., Çubuk H., Özkök R., Uysal R. 2006 – Reproduction properties of pike (*Esox lucius* L., 1758) population in Lake Karamik (Afyonkarahisar/Turkey) – Turk. J. Zool. 30: 27-34.

Bower C.E., Holm-Hansen T. 1980 – A salicylate-hypochlorite method for determining ammonia in seawater – Can. J. Fish. Aquat. Sci. 37: 794-798.

Cai Y.J., Summerfelt R.C. 1992 – Effects of temperature and size on oxygen consumption and ammonia excretion by walleye – Aquaculture 104: 127-138.

Casselman J.M., Lewis C.A. 1996 – Habitat requirements of northern pike (*Esox lucius*) – Can. J. Fish. Aquat. Sci. 53: 161-174.

Colt J., Orwicz K. 1991 – Modelling production capacity of aquatic culture systems under freshwater conditions – Aquacult. Eng. 10: 1-29.

Forsberg O.I. 1996 – Ammonia excretion rates from post-smolt Atlantic salmon, *Salmo salar* L., in land-based farms – Aquacult. Res. 27: 937-944.

Górny W. 1991 – The influence of water temperature on mortality, growth and cannibalism in the juvenile pike (*Esox lucius* L.) – Arch. Pol. Fish. 1: 27-31.

Jobling M. 1982 – A study of some factors affecting rates of oxygen consumption of plaice, *Pleuronectus platessa* L. – J. Fish Biol. 20: 501-516.

Jobling M. 1994 – Fish bioenergetics – Chapman & Hall, 300 p.

Kaushik S.J. 1980 – Influence of nutritional status on the daily patterns of nitrogen excretion in the carp (*Cyprinus carpio* L.) and rainbow trout (*Salmo gairdneri* R.) – Reprod. Nutr. Dev. 20: 1751-1765.

Kazuń K., Siwicki A.K. 2001 – Propiscin – a safe new anaesthetic for fish – Arch. Pol. Fish. 9: 36-43.

Kucska B., Müller T., Sári J., Bódis M., Bercsényi M. 2005 – Successful growth of pike fingerlings (*Esox lucius* L.) on pellet at artificial condition – Aquaculture 245: 227-230.

Mickiewicz M. 2006 – State of lake stocking in 2005 as compared to that in 2004 – In: Fisheries management in lakes, rivers and dam reservoirs in 2005 (Ed.) M. Mickiewicz, Wyd. IRS, Olsztyn: 13-27 (in Polish).

Paukert C.P., Klammer J.A., Pierce R.B., Simonson T.D. 2001 – An overview of northern pike regulations in North America – Fish. Manage. 26: 6-13.

Schmidt-Nielsen K. 1994 – Animal physiology: adaptation and environment – Cambridge University Press.

Szczepkowski M. 2006 – The impact of water temperature on the growth and survival of juvenile northern pike (*Esox lucius* L.) reared on formulated feed – Arch. Pol. Fish. 14: 85-93.

Szczepkowski M., Szczepkowska B., Wunderlich K. 2006 – Utilizing pike (*Esox lucius*) fry from artificial spawning to stock ponds – Komun. Ryb. 5: 1-3 (in Polish).

Timmermans G.A. 1979 – Culture of fry and fingerlings of pike, *Esox lucius* – EIFAC Tech. Pap. 35: 177-183.

Webb P.W. 1988 – "Steady" swimming kinematics of tiger musky, an esociform accelerator, and rainbow trout, a generalist cruisier – J. Exp. Biol. 138: 51-69.

Weihs D. 1973 – The mechanism of rapid starting of slender fish – Biorheology 10: 343-350.

Westers H. 1979 – Controlled fry and fingerlings productions in hatcheries – EIFAC Tech. Pap. 35: 32-52.

Westers H. 1981 – Fish culture manual for the state of Michigan - principles of intensive fish culture – Michigan Department of Natural Resources, Lansing, 101 p.

Wolnicki J., Górny W. 1997 – Effects of commercial dry diets and water temperature on growth and survival of northern pike, *Esox lucius* L., larvae – Pol. Arch. Hydrobiol. 44: 377-383.

Wolnicki J., Kamiński R. 1998 – Rearing pike hatchlings on a mass scale using starter – In: Lake fisheries, development, changes, difficulties (Ed.) A. Wołos. Wyd. IRS, Olsztyn: 83-90 (in Polish).

Yager T.K., Summerfelt R.C. 1994 – Effects of feeding frequency on metabolism of juvenile walleye – Aquacult. Eng. 13: 257-282.

Zakęś Z. 1999 – Oxygen consumption and ammonia excretion by pikeperch *Sander lucioperca* (L.) reared in a water recirculation system – Arch. Pol. Fish. 7: 5-55 (in Polish with English summary).

Zakęś Z., Demska-Zakęś K. 2005 – Oxygen consumption and ammonia excretion by Eurasian perch (*Perca fluviatilis* L.) reared under optimal thermal conditions – Arch. Pol. Fish. 13: 251-258.

Zakęś Z., Demska-Zakęś K., Jarocki P., Stawecki K. 2006 – The effect of feeding on oxygen consumption and ammonia excretion of juvenile tench *Tinca tinca* (L.) – Aquacult. Int. 14: 127-140.

Zakęś Z., Demska-Zakęś K., Kata K. 2003 – Rates of oxygen consumption and ammonia excretion of juvenile Eurasian perch *Perca fluviatilis* L. – Aquacult. Int. 11: 277-288.

Zakęś Z., Karpiński A. 1999 – Influence of water temperature on oxygen consumption and ammonia excretion of juvenile pikeperch, *Stizostedion lucioperca* (L.) reared in a recirculating system – Aquacult. Res. 30:109-114.

Žiliukiene V., Žiliukas V. 2006 – Feeding of early larval pike *Esox lucius* L. reared in illuminated cages – Aquaculture 258: 378-387.

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STRESZCZENIE

KONSUMPCJA TLENU I WYDALANIE AMONIAKU PRZEZ JUWENALNEGO SZCZUPAKA, *ESOX LUCIUS* L.

Celem badań było określenie wielkości konsumpcji tlenu (OC; mg O_2 kg^{-1} h^{-1}) i wydalania amoniaku (AE, mg TAN kg^{-1} h^{-1}; (TAN = NH_4^+-N + NH_3-N)) przez juwenalnego szczupaka podchowywanego w obiegach recyrkulacyjnych w dwóch temperaturach wody, tj. 20 i 24°C. Oszacowano również ilość tlenu potrzebną do zmetabolizowania 1 kg paszy (parametr OFR, kg O_2 kg^{-1} paszy dzień$^{-1}$) oraz ilość powstałego po zmetabolizowaniu tej dawki paszy amoniaku (parametr AFR, kg TAN kg^{-1} paszy dzień$^{-1}$). W czasie rutynowego, trwającego sześć tygodni podchowu ryb na paszy sztucznej, w każdym z wariantów temperatury wody przeprowadzono trzy dobowe pomiary OC i AE. Średnia masa ciała szczupaka w trakcie kolejnych pomiarów wynosiła 68 g (grupa I), 80 g (grupa II) i 90 g (grupa III; tab. 1). Konsumpcja tlenu ryb przetrzymywanych w 24°C była wyższa niż ryb podchowywanych w 20°C. Jednak jedynie w przypadku ryb o najmniejszej masie ciała (grupy I) różnice międzygrupowe były istotne statystycznie ($P < 0,05$; tab. 2). Stwierdzono, że zapotrzebowanie tlenowe szczupaka, zarówno w 20 jak i 24°C, malało wraz ze wzrostem masy ciała ryb, a różnice międzygrupowe były istotne statystycznie ($P < 0,05$). Przyrost masy ciała o 1 g, ryb podchowywanych w 20 lub 24°C, powodował zmniejszenie OC, odpowiednio o 2,36 i 2,78 mg O_2 kg^{-1} h^{-1}. Temperatura wody nie wpłynęła istotnie statystycznie na wartości AE stwierdzone w poszcze-

gólnych cyklach pomiarów metabolizmu szczupaka. Bardziej istotny okazał się wpływ masy ciała ryb na tempo ekskrecji amoniaku ($P < 0,05$; tab. 2). Dobowe profile OC i AE u ryb przetrzymywanych w 20 i 24°C miały zbliżony przebieg. Zaobserwowano jednak, że były one dość charakterystyczne dla poszczególnych grup wielkości ryb (rys. 1). Nie odnotowano istotnego wpływu temperatury wody na wartości OFR i AFR. Stwierdzono natomiast istotny wpływ masy ciała ryb na wielkość tych parametrów; wartości OFR i AFR malały wraz ze wzrostem ryb ($P < 0,05$; tab. 3).