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THE IMPACT OF WATER TEMPERATURE ON SELECTED REARING INDICES OF JUVENILE WHITEFISH (*COREGONUS LAVARETUS* (L.)) IN A RECIRCULATING SYSTEM

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ABSTRACT. This study investigated the impact of water temperature on the growth, feed uptake, and oxygen consumption of juvenile whitefish, *Coregonus lavaretus* (L.), reared in a recirculating system. The fish used in the study had a mean initial weight of 7.9 ± 0.2 g and a mean body length of 8.9 ± 0.1 cm. The study was conducted at water temperatures of 20, 22, and 24°C (each group in replicates of four). The best weight gain and body length growth were obtained at the water temperature of 22°C. Increasing the temperature to 24°C caused a statistically significant decrease in fish growth rate ($P < 0.05$). The feed conversion ratios of the fish reared at water temperatures of 20 and 22°C were close at 0.89 and 0.90, respectively, while at the temperature of 24°C this ratio was statistically significantly higher at 1.17 ($P < 0.05$). Temperature was not found to have a statistically significant impact on fish survival or on the amount of feed consumed. Water temperature had an impact on oxygen consumption, and the mean value of this index at a temperature of 20°C (186.6 mg O_2 kg^{-1} h^{-1}) was significantly statistically lower ($P < 0.001$) than in the water at temperatures of 22 and 24°C, at which the mean values were 349.3 and 409.9 mg O_2 kg^{-1} h^{-1}, respectively. Based on the results obtained, it was confirmed that the upper thermal threshold during the rearing of whitefish juveniles is 22°C.

Key words: WHITEFISH (*COREGONUS LAVARETUS*), TEMPERATURE, GROWTH, OXYGEN CONSUMPTION, RECIRCULATING SYSTEM

INTRODUCTION

The current state of whitefish, *Coregonus lavaretus* (L.), in Polish waters can be described as dramatic. Following years of growth in recapture levels and the number of lakes inhabited by this species, its population numbers are currently declining drastically (Falkowski 2004). This also refers to water bodies that until recently were regarded as “whitefish” lakes, such as Lake Gołdopiwo in the Mazurian Lake District (Krzywosz 2002). The situation is similar in many European countries (Bogdanova 2004, Winfield et al. 2004). The causes of this are many, including water pollution,

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a lack of natural spawning grounds, and predatory pressure from cormorants. The consequence of low recapture levels is the limited availability of stocking material and a decrease in stocking quantity (Mickiewicz 2004). One possible way to improve this situation would be to maintain a spawning stock in ponds, as this would allow for the continuous production of stocking material (Dobosz and Kuźmiński 1997, Atałap and Krzywosz 1999). In many instances, however, keeping whitefish in ponds subjects them to the risk of substantial losses from disease and environmental threats (Atałap, pers. comm.). This suggests that it may be advantageous to conduct some of the activities connected with rearing a brood stock and producing stocking material in a recirculating system, which permits ensuring desired rearing conditions. When applied to pikeperch, *Sander lucioperca* (L.), a species that is also susceptible to manipulation and has specific environmental needs, these measures produced good results and permitted creating a brood stock under fully controlled conditions (Szczepkowski and Zakęś 2003).

In order to realize this goal, it is necessary to discover all of the factors that can have an impact on the results of rearing, including the environmental requirements of this fish at different stages of its ontogenic development. In the case of whitefish, which is a cold-water species (Szczerbowski 2000, FishBase 2004), a crucial aspect of developing biotechniques is determining the impact temperature has on rearing indicators. This is especially important as regards the upper thermal limit tolerated by this fish. The aim of the present study was to determine the impact water temperature had on the results of rearing juvenile whitefish, including feed and oxygen consumption.

MATERIALS AND METHODS

The study was conducted in 2004 at the Dgał Experimental Hatchery in Pieczarki of the Inland Fisheries Institute in Olsztyn. Eyed-stage whitefish eggs obtained from spawners from Lake Gaładuś in the Suwałki Lakelands (northeast Poland) were transported just before hatching to the Dgał facility, where initial rearing was conducted. The fish obtained were used in the present study. These were juvenile whitefish aged five months (mean body weight 7.9 ± 0.2 g and body length 8.9 ± 0.1 cm). The study was performed in three recirculating systems equipped with rearing tanks with a volume of 50 dm^3 and at three water temperatures – 20, 22, and 24°C (groups T20, T22, and T24; each in replicates of four). The fish were moved to an interconnected experimental recirculating system with an initial water temperature of 17.6°C. Next, the systems were disconnected and over a 48-hour period the applied temperatures of 20, 22, and 24°C (rearing period – 35 days) were achieved. During the experiment, the water temperature in the systems was regulated with Dixell XR 20C thermostats (Italy) within a range that did not exceed ± 0.1°C. Each tank was stocked with 30 whitefish specimens, and the applied water flow rate was 4 dm^3 min^{-1}. The tanks were illuminated 24 hours day^{-1} at a light intensity range of 1100 to 2697 lx. Feeding was begun the moment the applied rearing temperature was achieved. The whitefish were fed to satiation with Nutreco formulated feeds for salmonid fish (Trouvit, France); for the first nine days they were fed Nutra Amino Balance 2.0 (54% protein, 18% fat), followed by Nutra Amino Balance 0 (54% protein, 18% fat) until the conclusion of the experiment. The feed was delivered manually from six to eight times a day between 07:00 and 19:00. The tanks were cleaned of waste and feces as necessary every three to four days. Every two days the quantity of feed consumed was calculated as the difference between the initial quantity of feed delivered and that remaining in each tank. The water content of nitrogen compounds – total ammonia nitrogen (TAN= NH_4^+-N + NH_3-N) and nitrites (NO_2-N), were measured twice weekly. Beginning on day 11 of rearing, the oxygen concentration (mg O_2 dm^{-3}) at the inflow and outflow of the tanks was measured daily at 16:00. Water oxygen content was measured to the nearest 0.01 mg O_2 dm^{-3} with a PCD 5500 oxygen meter (Eutech Instruments). Based on this, the oxygen consumed (OC; mg O_2 kg^{-1} h^{-1}) by the fish was calculated according to the following formula:

$$OC = (OC_{in} - OC_{out}) \times Q \times B^{-1}$$

where: OC_{in} and OC_{out} – oxygen concentration at the inflow and outflow (mg O_2 dm^{-3}), Q – water flow rate (dm^3 h^{-1}), B – fish biomass (kg).

Fish body weight (BW ± 0.1 g) and total length (Lt ± 0.1 cm) and body length (Lc ± 0.1 cm) were measured at the beginning and end of the study. A total of 15 fish were measured from each tank. The fish selected for measurements were anesthetized with Propiscin (Kazuń and Siwicki 2001) at concentrations of 0.5-0.8 cm^3 dm^{-3}. Additionally, on day 17 of rearing monitoring measurements were conducted and all of the fish from each tank were weighed. These measurements served to calculate the following:

– feed conversion ratio (FCR; the quotient of the feed delivered (g) divided by fish biomass gain (g));
– Fulton condition coefficient (K) according to the formula:

$$K = 100 \times BW \times Lc^{-3}$$

where: BW – body weight (g), Lc – body length (cm);
– specific growth rate (SGR; % d^{-1}) according to the formula:

$$SGR = 100 \times (\ln BW_f - \ln BW_b) \times T^{-1}$$

where: BW_f and BW_b – final and beginning body weight (g), T – rearing time (days).

Statistical analyses were performed with Statistica 5.0 PL. The significance of differences between groups was tested with ANOVA (Tukey's post-hoc test) at a level of significance of $P \leq 0.05$.

RESULTS

Throughout the study, the ammonia content did not exceed 0.23 mg TAN dm^{-3} while nitrites were not higher than 0.089 mg NO_2-N dm^{-3}. The pH of the water ranged from 7.94 to 8.16. The highest mean body weight was obtained by the fish in group T22, which was 26.5 g at the conclusion of the experiment. The body weights of the fish in groups T20 and T24 were lower at 25.6 g and 23.1 g, respectively, with the latter differing significantly statistically from the other groups (Table 1; $P < 0.05$).

TABLE 1

Final results from rearing juvenile whitefish at different water temperatures (mean values ± SD)

	Water temperature (°C)		
	20	22	24
Body weight (g)	25.61a ± 0.87	26.50a ± 2.18	23.07b ± 0.90
Body length (cm)	12.41a ± 0.60	12.45a ± 0.73	11.88b ± 0.74
Specific growth rate (SGR; % d^{-1})	3.59 ± 0.24	3.46 ± 0.19	3.15 ± 0.32
Fulton condition coefficient – K	1.33 ± 0.08	1.36 ± 0.09	1.36 ± 0.09
Quantity of feed delivered (% fish biomass d^{-1})	3.16 ± 0.87	3.40 ± 0.91	3.43 ± 0.81
Feed conversion ratio – FCR	0.89a ± 0.05	0.90a ± 0.06	1.17b ± 0.19
Survival (%)	90.8 ± 3.2	95.8 ± 6.3	86.7 ± 7.2

Values with different letters in the same row differ significantly statistically ($P \leq 0.05$)

The mean daily increase in body weight decreased as temperature increased from 3.59% d^{-1} at 20°C to 3.15% d^{-1} at 24°C. The differences among the groups were not statistically significant ($P > 0.05$). The final body length attained by the fish at the conclusion of the study was also the lowest in the group reared at 24°C and was statistically significantly lower than the other two groups (Table 1; $P < 0.01$). In all of the groups the condition coefficient of the fish increased substantially from about 1.10 at the beginning of the study to about 1.35 at the end of it; however, the differences among the groups were not statistically significant (Table 1; $P > 0.05$).

Fish survival was high and ranged from 95.8% in group T22 to 86.7% in group T24, and the differences were not statistically significant ($P > 0.05$). The values of the feed conversion ratio (FCR) were very similar in groups T20 and T22 (0.89 and 0.90, respectively), but that for group T24 was statistically significantly higher at 1.17 ($P < 0.05$). As the water temperature increased so did the amount of feed consumed by the fish per day. In the T20 group, the fish consumed an average of 3.16% of their biomass, while in the T24 group they consumed 3.43% of their biomass, but the differences noted were not statistically significant ($P > 0.05$). Simultaneously, throughout the study the amount of feed consumed daily decreased as fish body weight increased (Fig. 1).

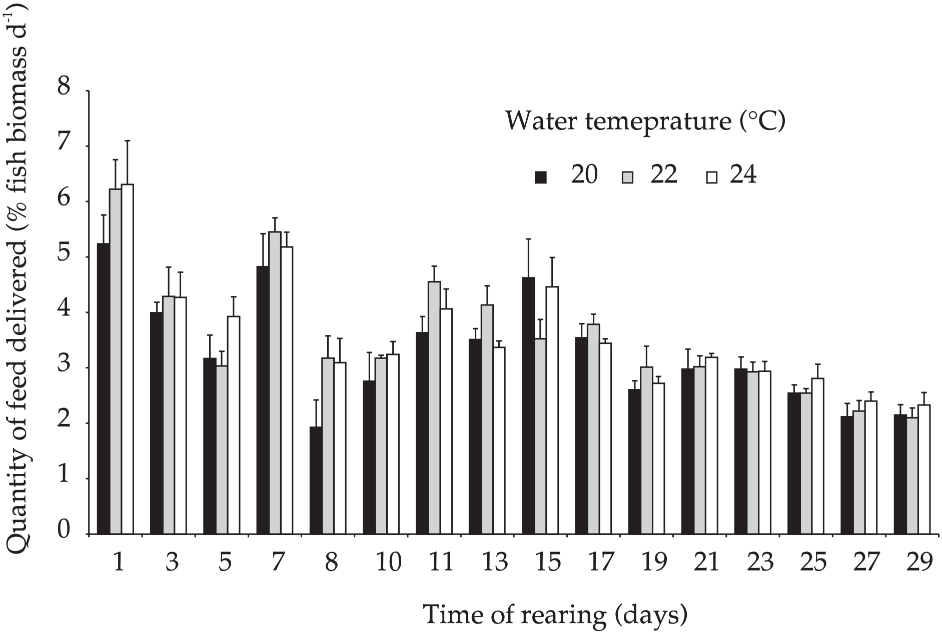

Fig. 1. Juvenile whitefish feed consumption at different water temperatures (mean ± SD).

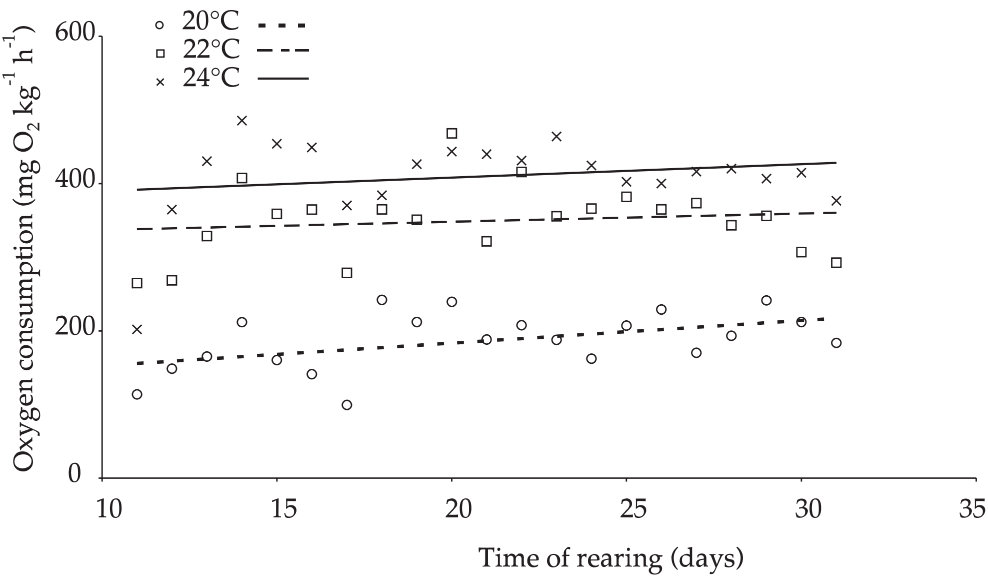

Fig. 2. Oxygen consumption of juvenile whitefish reared at various temperatures.

Increasing water temperature had a substantial impact on the amount of oxygen consumed by the fish, with the fish from group T24 using the most at a mean of 409.9 ± 56.8 mg O_2 kg^{-1} h^{-1}. The least oxygen was used by group T20 at 186.6 ± 40.0 mg O_2 kg^{-1} h^{-1}. The differences in oxygen consumption between group T24 and the other groups were statistically significant ($P < 0.001$) (Fig. 2).

DISCUSSION

Water temperature is one of the most significant environmental factors influencing the life processes of fish such as growth, metabolism, or gonad development (Kamler 1992, Hung et al. 1993). In the case of salmonid fishes, water temperature can limit possibilities of rearing them to facilities that have access to cool waters. The study presented here also indicated that temperature had a strong impact on the rearing of whitefish juveniles in a recirculating system. It can be inferred from these results that the upper thermal limit for rearing whitefish fry is 22°C. Temperatures above this caused slower rates of weight gain and body length growth in the fish. Other authors obtained slightly lower optimal temperatures for whitefish larval growth: according to Koskela and Eskelinen (1992), the range was from 19.3 to 20.6°C; and to Knjazeva and Kostuynichev (1991, cited in Bogdanova 2004) – 20°C. According to these same authors, the optimal temperature for commercial whitefish rearing is between 17 and 20°C, while the upper limit is 21°C. It should be borne in mind that in addition to differences at various stages of ontogenic development, fish originating from different populations can exhibit varied thermal preferences (Kucharczyk et al. 1994).

In the case of juvenile whitefish, increasing water temperature above 22°C resulted in less efficient feed utilization even though it was delivered only in quantities that were fully consumed by the fish. Adapting to new conditions doubtlessly also had an impact on the degree to which the fish consumed feed. This is evident in the substantial fluctuations in feed consumption noted in the first ten days of the study. Following this, the quantities of consumed feed decreased proportionally with fish growth. Koskela et al. (1997) confirmed the occurrence of significant differences in whitefish growth rates in the initial period following the shift in the manner of feeding as well as the disappearance of these differences in further rearing, which was related to adapting to new conditions. The decrease in feed consumption and the resulting decrease in growth potential as body weight increased were observed in the current study and are characteristic of fish ontogenesis (Jobling 1983).

Increased water temperature had an equally significant impact on the oxygen consumption of juvenile whitefish. From this perspective, it was most advantageous to rear the fish in water at a temperature of 20°C, as increases in water temperature caused substantial increases in oxygen requirements. In the current study, however, the differences in whitefish oxygen consumption could also have been due to, in addition to temperature, differences in the quantities of feed ingested, fish size, and stock density. This refers especially to the final stage of the study. Increased fish oxygen consumption along with decreasing feed ingestion and an increase in fish weight apparently caused by the increase in the activity of the fish (active metabolism) was observed during the study in all temperature groups. It is possible that an additional factor had an impact on this phenomenon; namely, the stocking density at the conclusion of the experiment was nearly 20 kg m^{-3} and the rearing tanks were too small in relation to the size of the fish.

The results presented in this paper indicate that the lethal temperature for juvenile whitefish is above the 24°C threshold and even long-term rearing (exceeding 30 days) at this temperature does not result in increased mortality. It bears remembering that in the current study the thermal conditions were stable. Additionally, other water quality parameters which are important to life processes (*e.g.*, oxygen concentration, pH, content of nitrogen compounds) were within the optimal ranges and remained at a relatively stable level. Under natural conditions, or those that mimic them closely (ponds), changes in water quality parameters are more dynamic, which means that the whitefish juveniles are more sensitive to thermal differences. The lethal temperature identified by Schulz and Schurno (1994) for Pomeranian whitefish from the Bay of Pomerania is also above the 24°C threshold at 26°C. According to Flüchter (1980), whitefish larvae will feed even at a temperature of 26°C, which suggests that the lethal temperature for larval whitefish is somewhat higher.

The study presented in this paper indicates that there is good potential for rearing juvenile whitefish in recirculating systems at a temperature close to 20°C. In the case of larvae, higher temperatures during initial tank rearing permitted obtaining substantially better fish growth in further pond rearing (Dostatni et al. 1999) and in consequence larger stocking material. This, in turn, may be a significant factor in the effects of stocking (Jokikokko et al. 2002, Amtstaetter and Willox 2004). The impact of high temperatures on the further development of the fish, including their maturation, should be determined. According to Bogdanova (2004), high temperatures during the pre-spawning period caused anomalies in gonad development in whitefish spawners, which can result in reduced reproductive success.

CONCLUSIONS

1. The water temperature for rearing juvenile whitefish in recirculating systems should not exceed 22°C. Above this temperature declines were noted in the fish growth rate and the feed conversion ratio.
2. The lethal water temperature for whitefish juveniles reared in a recirculating system is that which exceeds 24°C.
3. As the temperature rises above 20°C, whitefish juvenile oxygen consumption increases significantly. This should be taken into consideration in the principles that guide rearing.

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STRESZCZENIE

WPŁYW TEMPERATURY WODY NA WYBRANE WSKAŹNIKI PODCHOWU JUWENALNEJ SIEI (*COREGONUS LAVARETUS* (L.)) W OBIEGU RECYRKULACYJNYM

Badano wpływ temperatury wody na wzrost, pobieranie paszy oraz konsumpcję tlenu przez juwenalną sieję, *Coregonus lavaretus* (L.), podchowywaną w obiegu recyrkulacyjnym. Eksperyment przeprowadzono w trzech wariantach w temperaturach wody: 20, 22 i 24°C. Do badań użyto ryb o średniej masie 7,9 ± 0,2 g i długości ciała 8,9 ± 0,1 cm, a każdy wariant wykonano w czterech powtórzeniach. Najlepsze przyrosty masy i długości ciała uzyskano w wodzie o temperaturze 22°C. Podwyższenie temperatury do 24°C spowodowało istotne statystycznie obniżenie tempa wzrostu ryb ($P < 0,05$) (tab. 1). Współczynnik pokarmowy pasz w wariantach 20 i 22°C był zbliżony i wyniósł odpowiednio 0,89 i 0,90, zaś w temperaturze 24°C był statystycznie istotnie wyższy i osiągnął wartość 1,17 ($P < 0,05$). Nie stwierdzono statystycznie istotnego wpływu temperatury na przeżywalność ryb i ilość spożywanej przez nie paszy (rys. 1). U badanych ryb temperatura wody wpływała na konsumpcję tlenu, przy czym jej średnia wartość w wodzie w temperaturze 20°C (186,6 mg O_2 kg^{-1} h^{-1}) była statystycznie istotnie niższa ($P < 0,001$) niż w wodzie o temperaturach 22 i 24°C, gdzie jej średnie wartości wyniosły odpowiednio: 349,3 i 409,9 mg O_2 kg^{-1} h^{-1} (rys. 2). Na podstawie uzyskanych wyników ustalono, że górny próg termiczny w czasie chowu narybku siei wynosi 22°C.