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EFFECTS OF TEMPERATURE ON SURVIVAL, DEFORMATIONS RATE AND SELECTED PARAMETERS OF NEWLY HATCHED LARVAE OF THREE RHEOPHILIC CYPRINIDS (GENUS *LEUCISCUS*)*

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K e y w o r d s: incubation temperature, hatching success, abnormalities, *Leuciscus leuciscus*, *Leuciscus idus, Leuciscus cephalus*.

A b s t r a c t

Experiments were conducted to determine full range of tolerated and optimal water condition for eggs incubation of three species from genus *Leuciscus* i.e: dace *Leuciscus leuciscus* (L.), ide *Leuciscus idus* (L.), and chub *Leuciscus cephalus* (L.). Spawners were caught from rivers of the northern (Pasleka River drainage) and central (Pilica River drainage) parts of Poland. Fertilized eggs were incubated under controlled conditions at ten different constant temperatures ranging from 4.5 to 29.0°C. The optimal temperature ranges for the incubation of dace, ide and chub eggs were 7.5 to 12.3°C; 15.7°C and 19.0 to 23.0°C, respectively (considering hatching percentage, incidence of abnormalities and size of hatched larvae), which are close to the water temperature during spawning season. This study also reveals that embryos of studied species can adapt to increasing water temperature due to global warming up to 23.0°C (dace and ide) and 27.5°C (chub). Besides, some inter-population differences in the response to temperature were observed.

WPŁYW TEMPERATURY WODY NA PRZEŻYWALNOŚĆ, ODSETEK DEFORMACJI ROZWOJOWYCH ORAZ WYBRANE PARAMETRY LARW TRZECH GATUNKÓW KARPIOWATYCH RYB REOFILNYCH Z RODZAJU *LEUCISCUS*

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S ł o w a k l u c z o w e: temperatura inkubacji, procent wyklucia, deformacje rozwojowe, *Leuciscus leuciscus*, *Leuciscus idus, Leuciscus cephalus*.

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Abstrakt

Przeprowadzono badania określające zakres temperatur tolerowanych i optymalnych dla inkubacji ikry trzech gatunków należących do rodzaju *Leuciscus*: jelca *Leuciscus idus* (L.), jazia *Leuciscus idus* (L.) i klenia *Leuciscus cephalus* (L.). Tarlaki pozyskano z Polski północnej (rzek dorzecza Pasłęki) oraz centralnej (rzek dorzecza Pilicy). Zapłodnioną ikrę inkubowano w warunkach kontrolowanych, w szerokim zakresie stałych temperatur wynoszącym od 4,5 do 29.0°C. Biorąc pod uwagę procent wyklucia, odsetek zdeformowanych larw oraz ich rozmiar optymalnymi warunkami inkubacji dla ikry jelca i klenia okazały się zakresy odpowiednio 7.5–12.3°C i 19.0–23.0°C. Dla jazia była to temperatura 15.7°C. Uzyskane wartości temperatur optymalnych są zbliżone do temperatur występujących podczas tarła. Przeprowadzone badania ujawniają również, że rozwijające się embriony badanych gatunków są w stanie tolerować temperaturę wody sięgającą 23.0°C (jelec, jaź) oraz 27.5°C (kleń). W trakcie doświadczenia zaobserwowano również pewne międzypopulacyjne różnice w badanych parametrach.

Introduction

Among the inland freshwater fish species of Europe, rheophilic cyprinids are one of the most sensitive to changes in the environment that stem primarily from constructions on rivers and pollution (SAUNDERS et al. 2002). Systematic studies of the rivers of Poland indicate there are permanent access limitations for many rheophilic fish including ide, *Leuciscus idus* (L.), dace, *Leuciscus leuciscus* (L.) and chub, *Leuciscus cephalus* (L.) (WITKOWSKI et al. 2004, PENCZAK et al. 2004). This is why interest is growing in the restoration of this species to European waters, and, consequently, efforts in the field of aquaculture are intensifying. Most of research aimed at developing reproductive biotechnologies (e.g.: KUCHARCZYK 2002, KREJSZEFF et al. 2008, 2009, ŻARSKI et al. 2009, CEJKO et al. 2010, HAKUĆ-BŁAŻOWSKA et al. 2010, TARGOŃSKA et al. 2010), and nursery techniques for dace, ide and chub (i.e. SHIRI HARZEVILI et al. 2003, 2004, KUJAWA 2004, KUPREN et al. 2008a, ŻARSKI et al. 2008). One of the main aspects of these researches are determination of the thermal conditions of incubation and rearing of fish embryos and larvae. Data concerning the thermal preferences of the different fish species is also very important in the context of overall warming of the water due to climatic changes (DAUFRESNE and BOËT 2007).

Temperature directly influences the developmental rate and development is faster at increasing temperature (KOKUREWICZ 1969, HERZIG and WINKLER 1986, KAMLER 1992, KUCHARCZYK et al. 1997, DAS et al. 2008, KORWIN-KOSSAKOWSKI 2008). However increase in temperature beyond tolerates thermal limits may also elevate the mortality and the percentage of abnormal embryos. In general, thermal limits are narrower for early stages of development (embryonic and larval). Later stages (juvenile and adults) are clearly less stenothermal (ELLIOTT 1981, COSSINS and BOWLER 1987, KUCHARCZYK et al.

1998, BERMUDES and RITAR 1999, ŻARSKI et al. 2010). Thermal history or acclimation temperature may also affect the temperature tolerance of embryos and larvae (KOKUREWICZ 1971, KUJAWA et al. 1997).

The influence of water temperature on chosen aspects of egg incubation for dace or ide has been studied by KENNEDY (1969), FLOREZ (1972), MILLS (1980), RECHULICZ et al. (2002), KUPREN et al. (2008a). Data on chub are presented by PENAZ (1968), PENAZ and STERBA (1969), ECONOMOU et al. (1991), CALTA (2000), ELLIOTT (1981) and KUPREN et al. (2008a). Most of these reports are incomplete because in most cases these data do not show full range of tolerated temperatures, in which normal development of embryos is possible, or they are limited to information concerning fish from given specific populations. However many fish species have a wide geographical range of occurrence, and the thermal conditions to which the particular populations are adapted may differ considerably (KOKUREWICZ 1971, MANN 1996, KUCHARCZYK et al. 1997). Besides data concerning thermal tolerance of developing eggs together with information concerning hatched individuals (i.e. abnormalities, size of body) would allow determine range of optimal temperatures for incubation (KOKUREWICZ 1969, KAMLER 1992). These information are very important not only for practical purposes but also from the physiological and ecological point of view.

This study investigated the effect of incubation temperature conditions on mortality, abnormalities of newly hatched larvae and body size parameters of newly hatched larvae of three rheophilic cyprinids from the genus *Leuciscus*, important species for European conservational aquaculture.

Materials and Methods

Spawners of dace *Leuciscus leuciscus* (L.), ide *Leuciscus idus* (L.) and chub *Leuciscus cephalus* (L.) were caught at different times before natural spawning (between February and June) from two parts of Poland: rivers of central Poland (Pisa River drainage) (dace: 10 females with body weight of 250–345 g and 12 males with body weight of 70–300 g; ide: 25 females of 820–1200 g and 14 males of 320–760 g; chub: 20 females of 290–365 g and 16 males of 136–350 g) and northern part of Poland (Pasleka River drainage) (dace: 13 females with body weight of 240–295 g and 10 males 80–280 g; ide: 12 females of 780–1150 g and 14 males of 300–650 g; chub: 14 females with body weight of 300–390 g and 12 males with body weight of 160–350 g). After collection the fishes were transported to the hatchery of the Department of Lake and River Fishery of the University of Warmia and Mazury and placed in 1000 dm^3 separate tanks with the possibility of thermal regulation, aeration and controlled

photoperiod (KUJAWA et al., 1999). For the purpose of spawning synchronization all obtained females and males of each species were subjected to hormonal stimulation. In the case of all the species Ovopel (Unic – Trade, Hungary) (HORVATH et al. 1997), in two doses of 0.2 and 1.0 granules per kg was used as the preparation stimulating maturation. All handling procedure was made using the methods described by KUCHARCZYK et al. (2005) for common bream (*A. brama* L.). The interval between the injections was 24 h for dace and ide and 12 h for chub. Following the second hormonal injection the water temperature in the tanks with spawners was increased to 12.0°C for dace, 14.5°C for ide and 18°C for chub (KREJSZEFF et al. 2008, 2009, KUCHARCZYK et al. 2008, ŻARSKI et al. 2009). That temperatures occur during spawning (MANN 1996) and are recommended for reproduction conducted under controlled conditions (KUPREN et al. 2008a, KUCHARCZYK et al. 2008, TARGOŃSKA et al. 2008). Before manipulations, spawners were anaesthetized in a solution of 2-phenoxyethanol (0.5 mg dm^{-3}) (Sigma-Aldrich, Germany). Milt was collected with plastic syringes and kept at 4°C before further treatment. Females were checked every three hours between 20 and 48th hours after resolving injections. Eggs were collected to plastic vessel end were next fertilized using dry method with pooled sperm collected from at least a few males.

Conditions of incubation

Fertilized eggs of the three studied species were incubated next at ten constant temperatures (4.5; 7.5; 9.5; 12.3; 15.7; 19.0; 23.0; 25.0; 27.5 and 29.0°C). The time of thermal adaptation to the given constant temperature was 1.5°C h^{-1}. Each experimental variant consisted of two lighted and aerated 40 dm^3 aquaria submerged in the 1000 dm^3 tank with water. The bath (1000 dm^3 tank) was equipped with controllable heater adjusting water temperature with an accuracy up to 0.1°C. In each of the aquaria the eggs were incubated on two Petri dishes (150–180 eggs/dish). The dishes were additionally placed in baskets of fine mesh. Water temperature during incubation was measured with the accuracy of 0.1°C four times a day. For secure stable and good conditions of incubation (oxygen saturation > 80%, ammonia and nitrite < 0.1 and 0.05, respectively) the water in the aquaria were changed daily (min 50% of volume). A fixed photoperiod of 12L:12D (Light: Dark) was maintained with light exposure from 7.00–19.00 h.

Hatching success in individual experimental groups was expressed as the ratio of hatched, normal developed embryos to the number of incubated eggs. The percentage of hatched, deformed embryos (abnormalities) (i.e.: a curvature of the spine, shortened body, shortened yolk sac, deformed skull, deformed eyes and cardiac edema) was also recorded.

Morphological measurements after hatching

At the moment of mass hatching (about 50% embryos hatched) 30 individuals were sampled from each replicate for morphological measurements. Larvae were scanned using DP-Soft software from SZ CPV Olympus stereoscopic microscope mounted with Olympus DP 12 digital camera connected to a computer. The total length, height and length of the yolk sac were measured with the accuracy of 0.01 mm. The measurements of the yolk sac were used for determination of its volume (BLAXTER and HEMPEL 1963).

Statistical analysis

Differences between groups regarding mean diameter of hydrated eggs (50 eggs from each group were tested), survival, embryonic total length and volume of yolk sac were analyzed with analysis of variance (ANOVA) and Tuckey's *post hoc* test ($\alpha = 0.05$). Survival and abnormalities percentages were normalised using arcsine transformation (SOKAL and ROHLF 1969). The differences were regarded as significant at $p < 0.05$.

Results

Mean diameter of hydrated eggs of dace, ide and chub were clearly diferentiated. Mean diameter of eggs of each species which were originated from two populations located in different parts of Poland did not differ significantly (Table 1).

Table 1
Mean diameter of hydrated eggs of dace, ide and chub originated from northern (N) and central (C) Poland. Means (± SD) with different letters are significantly different (Tukey test P < 0.05)

Species	Eggs diameter [mm]
Dace (N)	$2.23 + 0.12^a$
Dace (C)	$2.19 + 0.06^a$
Ide (N)	$2.28 + 0.12^b$
Ide (C)	$2.26 + 0.12^b$
Chub(N)	$1.89 + 0.06^c$
Chub(C)	$1.89 + 0.07^c$

Hatching success and abnormalities

The water temperature range the incubated eggs were exposed to was found to affect the hatching success and incidence of abnormalities (Figure 1 and Figure 2, Table 2). Dace embryos from northern part of Poland hatched at temperatures from 7.5 to 23.0°C. Incubation temperature of 23.0°C was lethal for embryos from central part of Poland. Generally the best results of dace incubation (to 61.3% of survival) were observed in temperatures from 9.5 to 15.7°C (Figure 2, Table 2). Survival rate in others treatments was significantly lower. Significant highest incidences of abnormalities (ranging 11.4%) were at sublethal temperatures (19.0 and 23.0°C for fish from central and northern Poland, respectively) – Table 2.

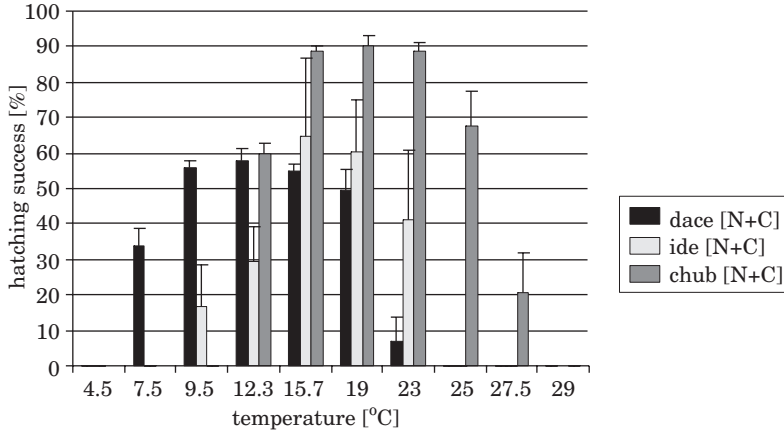

Fig. 1. The hatching success of dace, ide and chub larvae. Means (± SD) from two studied populations (N+C)

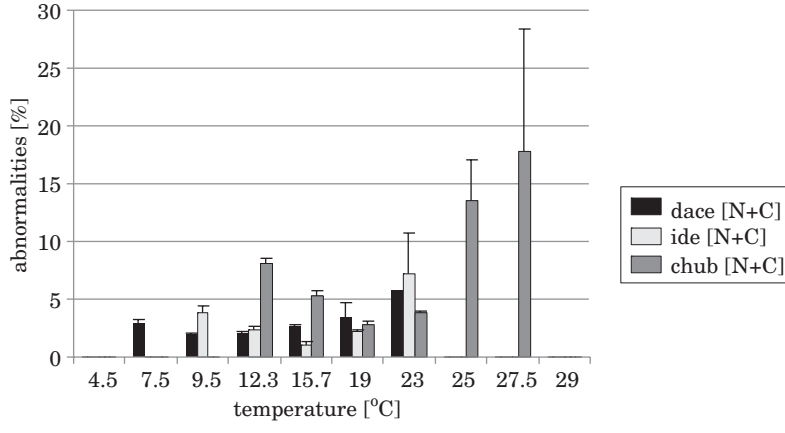

Fig. 2. Abnormalities of newly hatched dace, ide and chub larvae originated from hatching in different temperatures. Means (± SD) from two studied populations (N+C)

Table 2

The hatching success and abnormalities of newly hatched dace, ide and chub larvae originated from northern (N) and central (C) hatching in different temperatures (treatments with viable embryos). Means (± SD) in the same column with different letters are significantly different ($P < 0.05$)

Species	Temperature [°C]	Hatching success [%]	Abnormalities [%]
Dace (N)	7.5	29.0 ± 2.2^{c}	$1.2 + 0.3^{c}$
	9.5	54.4 ± 10.7^{a}	2.0 ± 0.13^{d}
	12.3	54.5 ± 2.1^{a}	2.1 ± 0.2^{cd}
	15.7	52.8 ± 7.5^{ab}	2.4 ± 0.7^{cd}
	19.0	55.5 ± 5.8^{a}	2.0 ± 0.1^{d}
	23.0	13.8 ± 3.2^{d}	11.4 ± 1.1^{a}
Dace (C)	7.5	38.7 ± 7.9^{b}	2.7 ± 0.2^{cd}
	9.5	57.6 ± 3.7^{a}	1.9 ± 0.3^{d}
	12.3	61.3 ± 5.5^{a}	2.0 ± 0.3^{d}
	15.7	57.0 ± 4.4^{a}	2.8 ± 0.3^{cd}
	19.0	43.9 ± 5.5^{b}	4.7 ± 0.5^{b}
Ide (N)	9.5	28.5 ± 3.4^{e}	4.4 ± 0.6^{b}
	12.3	39.2 ± 1.7^{d}	2.0 ± 0.3^{bcd}
	15.7	86.8 ± 5.0^{a}	1.3 ± 0.2^{cd}
	19.0	75.1 ± 4.2^{b}	1.9 ± 0.3^{bcd}
	23.0	60.7 ± 7.3^{c}	10.7 ± 1.6^{a}
Ide (C)	9.5	4.5 ± 2.7^{f}	3.4 ± 0.3^{b}
	12.3	20.0 ± 1.5^{e}	2.7 ± 0.2^{bc}
	15.7	42.4 ± 1.9^{d}	0.8 ± 0.3^{d}
	19.0	45.3 ± 2.9^{d}	2.4 ± 0.1^{bcd}
	23.0	22.0 ± 2.6^{e}	3.8 ± 0.6^{b}
Chub (N)	12.3	57.4 ± 2.4^{c}	6.8 ± 0.5^{c}
	15.7	90.0 ± 1.4^{a}	3.2 ± 0.8^{d}
	19.0	93.3 ± 0.7^{a}	2.9 ± 0.2^{d}
	23.0	90.9 ± 0.9^{a}	3.5 ± 0.4^{d}
	25.0	58.1 ± 2.9^{c}	20.0 ± 2.1^{b}
	27.5	31.6 ± 3.8^{d}	28.4 ± 2.7^{a}
Chub (C)	12.3	62.6 ± 3.3^{c}	9.3 ± 0.5^{c}
	15.7	87.9 ± 3.2^{a}	7.4 ± 0.8^{c}
	19.0	87.3 ± 2.0^{a}	2.7 ± 0.2^{d}
	23.0	$86.3 + 1.7^{a}$	4.0 ± 0.12^{d}
	25.0	77.4 ± 2.2^{b}	7.1 ± 0.4^{c}
	27.5	9.8 ± 4.5^{de}	7.4 ± 0.9^{c}

Hatching of ide originating from two parts of Poland was observed in almost identical temperatures, as in dace (9.5–23.0°C). The highest mean eggs survival was observed at 15.7 and 19.0°C (75.1–86.8% for fish from north part of Poland and 42.4%–45.3% for fish from central part), lowest was at 9.5°C (28.5% and 4.5% for fish from north and central Poland) – Table 2. Level of morphological abnormalities was highest at 23.0°C. For ide originating from north part of Poland mean percent of abnormalities reached 10.7% and was almost three times higher than registered in fish from central Poland at the

same temperature. This rate was also significantly different from that observed in other treatments (Table 2).

Chub embryos from two studied part of Poland had the same range of tolerated temperatures ranging from 12.3 to 27.5°C. The highest survivals (86.3 to 93.3%) were at temperatures from 15.7 to 23.0°C (Table 2), significantly different from others treatments. The favourable incubation temperatures (survival > 50%) ranged from 12.3 to 25.0°C (Table 2). The highest incidence of abnormalities reaching 28.4% (27.5°C, northern population) was noted at two (highest and lowest) limits temperature. Differences in percent of abnormal embryos were clearer among treatments of northern population (Table 2).

Total length and yolk sac volume of hatched embryos

Larval total length and yolk volume were related to temperature at hatch (Figure 3, Figure 4, Table 3). Total length of dace at hatching time ranged in different temperatures from 5.78 to 8.30 mm in northern population, and from 6.37 to 7.42 mm in central population (Table 3). Their yolk sac volumes reached 0.33–0.92 mm^3 and 0.26–0.49 mm^3, respectively). The highest mean total length was recorded in the larvae hatched from eggs incubated at 9.5 and 12.3°C. Embryos incubated in these regimes showed also the lowest yolk sac volume (Table 3).

The total length of ide larvae from northern population ranged from 6.01 to 7.23 mm, and their yolk sac volumes varied from 0.66 to 1.13 mm^3. The total length of ide from central Poland ranged from 5.89 to 7.52 mm, and their yolk sac volumes varied from 0.63 to 0.97 mm^3. The highest mean total length was

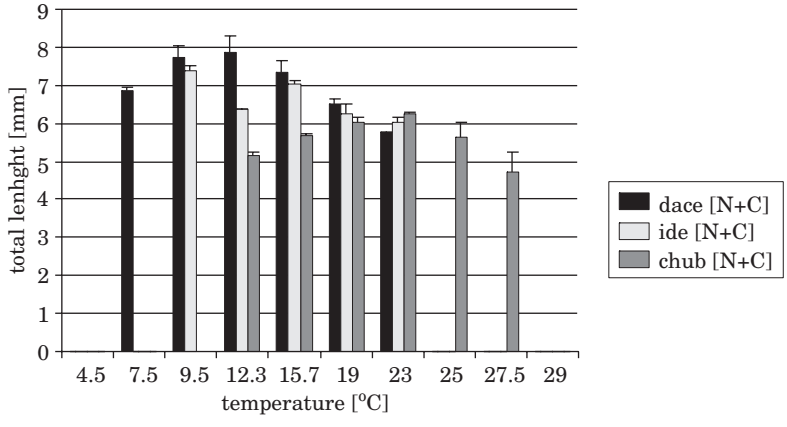

Fig. 3. Mean total length of dace, ide and chub larvae at the moment of hatching (50% individuals hatched). Means (± SD) from two studied populations (N+C)

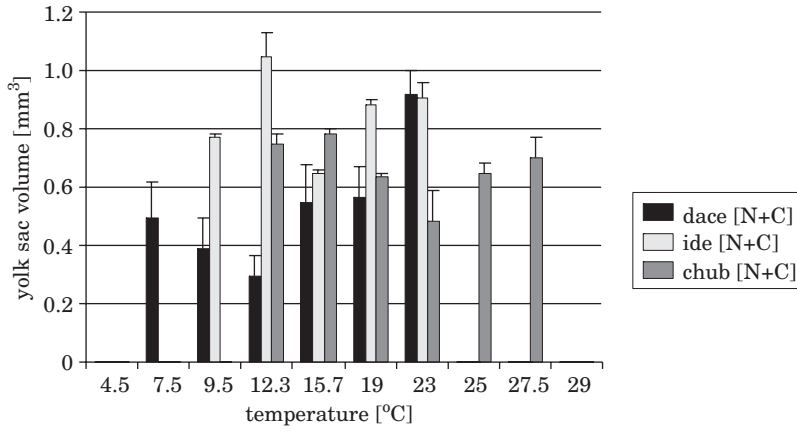

Fig. 4. Mean volume of the yolk sacs of dace, ide and chub larvae at the moment of hatching (50% individuals hatched). Means (± SD) from two studied populations

recorded in the larvae hatched from eggs incubated at 9.5 and 15.7°C. The lowest yolk sac volume was recorded in the individuals hatched from eggs kept at 15.7°C (Table 3).

The total length of chub from northern Poland reached from 4.20 to 6.28 mm at hatching time, with yolk sac volumes varied from 0.38 to 0.80 mm^3. In fish from central Poland respective size ranged from 5.24 to 6.22 mm, with yolk sac volumes ranged from 0.59 to 0.77 mm^3. Generally larvae obtained from 27.5°C were the smallest, while the fish hatched from eggs kept at 19.0°C and 23.0°C showed the highest mean total length. and the smallest yolk sac volume (Table 3).

Generally there were a significant decline of both hatching success and total length ($P < 0.05$) in all tested groups in extreme (sublethal) temperatures (Figure 1, Figure 3, Table 2, Table 3). The volume of yolk and incidence of abnormalities at hatching showed inverse but usually less clear tendency (Figure 2, Figure 4,Table 2 and Table 3). Inter-population differences in hatching success after incubation at the same water temperature were the most visible in the case of young ide (Table 2). Besides newly hatched ide and also chub from two different parts of Poland were characterized by very similar mean total length and yolk sac volume. Dace from north and central Poland were far more differentiated (Table 3).

Table 3

Mean total length and volume of the yolk sacs dace, ide and chub larvae at the moment of hatching (50% individuals hatched). Means (± SD) in the same column with different letters are significantly different (Tukey test $P < 0.05$).

Species	Temperature (°C)	Total lenght (mm)	Yolk sac volume (mm^3)
Dace (N)	7.5	6.94 + 0.20^{e}	0.62 + 0.22^{b}
	9.5	8.06 + 0.36^{a}	0.45 + 0.15^{c}
	12.3	8.30 + 0.41^{a}	0.33 + 0.07^{c}
	15.7	7.66 + 0.11^{b}	0.61 + 0.14^{b}
	19.0	6.63 + 0.28^{d}	0.65 + 0.08^{b}
	23.0	5.78 + 0.25^{e}	0.92 + 0.08^{a}
Dace (C)	7.5	6.76 + 0.10^{e}	0.37 + 0.03^{c}
	9.5	7.42 + 0.14^{b}	0.33 + 0.06^{c}
	12.3	7.39 + 0.41^{b}	0.26 + 0.07^{c}
	15.7	6.99 + 0.20^{c}	0.49 + 0.11^{bc}
	19.0	6.37 + 0.27^{d}	0.48 + 0.13^{bc}
Ide (N)	9.5	7.23 + 0.37^{ab}	0.78 + 0.22^{b}
	12.3	6.33 + 0.49^{e}	1.13 + 0.12^{a}
	15.7	7.13 + 0.26^{b}	0.66 + 0.13^{c}
	19.0	6.01 + 0.15^{d}	0.90 + 0.18^{b}
	23.0	6.18 + 0.20^{cd}	0.96 + 0.07^{b}
Ide (C)	9.5	7.52 + 0.24^{a}	0.76 + 0.27^{b}
	12.3	6.39 + 0.29*bc*	0.97 + 0.15^{b}
	15.7	6.95 + 0.20^{b}	0.63 + 0.24^{c}
	19.0	6.50 + 0.29^{bc}	0.87 + 0.09^{b}
	23.0	5.89 + 0.42^{d}	0.85 + 0.12^{b}
Chub (N)	12.3	5.01 + 0.15^{d}	0.78 + 0.08^{a}
	15.7	5.60 + 0.17^{c}	0.80 + 0.08^{a}
	19.0	5.90 + 0.23^{b}	0.62 + 0.07^{b}
	23.0	6.28 + 0.22^{a}	0.38 + 0.07^{c}
	25.0	5.29 + 0.19^{d}	0.68 + 0.13^{b}
	27.5	4.20 + 0.06^{e}	0.63 + 0.13^{b}
Chub(C)	12.3	5.26 + 0.32^{d}	0.71 + 0.09^{ab}
	15.7	5.73 + 0.19^{c}	0.77 + 0.11^{ab}
	19.0	6.18 + 0.20^{a}	0.65 + 0.04^{b}
	23.0	6.22 + 0.22^{a}	0.59 + 0.07^{b}
	25.0	6.01 + 0.14^{b}	0.62 + 0.10^{b}
	27.5	5.24 + 0.17^{d}	0.77 + 0.09^{ab}

Discussion

The results presented in this paper are the first data showed full range of tolerated temperatures for embryonic development of dace, ide and chub connected with data described hatched embryos after incubation conducted under the same condition. These results showed that embryos from genus *Leuciscus* have similar range of tolerated temperatures (about 15°C) but they are shifted towards higher or lower temperatures with different lower and

upper temperature limit for incubation. Chub embryos tolerated treatments with highest water temperature (up to 27.5°C), while dace embryos with the lowest (up to 7.5°C). It is undoubtedly correlated with different temperatures which occur during time of spawning (KOKUREWICZ 1971, MANN 1996). Dace usually beginning reproduction during early spring (February – April) as a one of first cyprinid species. Chub can reproduce one or few times in the year but usually started when water temperature is about 18.0°C (KOKUREWICZ 1971, MANN 1996, KREJSZEFF et al. 2008, 2010). The results obtained in the present research generally agree with previous data which indicated ranges of tolerated temperature for ide (FLOREZ 1972) but not for dace (MILLS 1980, KUCHARCZYK et al. 2002) and chub embryos (ELLIOTT 1981). The lowest tolerated temperature (7.5°C) for dace embryos was similar as observed in nature at spawning grounds (KENNEDY 1969, MILLS 1980). Upper tolerated thermal conditions (19.0 and 23.0°C) were few degrees higher than registered for dace originated from English (MILLS 1980) and Polish (KUCHARCZYK et al. 2002) waters. For the chub embryos ELLIOTT (1981) set the lower boundary temperature at 16.0°C while in our study it was 12.3°C. These evident differences occurred among fish from various population (in our experiment also between embryos of dace originating from two parts of Poland) may be caused by adaptation to their particular habitat, especially to the different thermal conditions experienced by the parents before and during spawning season (KOKUREWICZ 1971, KUCHARCZYK et al. 1997, KUJAWA et al. 1997, BERMUDES and RITAR 1999). Another reason may be a significant methodological differences used in cited papers like exposure of fertilized eggs on extremely low or high temperatures without no adaptation period (e.g. KUCHARCZYK et al. 2002).

Incubation of fish eggs in not favourable conditions may also result in premature hatching of smaller less developed larvae (KOKUREWICZ 1969, KAMLER 1992, RECHULICZ et al. 2002, KORWIN-KOSSAKOWSKI 2008). Newly hatched dace, ide and chub larvae were generally the largest at temperatures, which were similar to thermal water conditions during spawning. In other treatments the individuals leaving the egg shells usually were relatively smaller and had larger yolk sac. BLAXTER (1969) and KOKUREWICZ (1969) suggested that ideal incubation conditions (optimal temperatures) resulted in relatively large larvae, which are expected to be stronger and better swimmers. At optimum temperatures morphogenesis, growth of hatching glands, activations of their enzymes are the most harmonious (KOKUREWICZ 1969, KAMLER 1992). Differences observed in morphological parameters between studied species and also dace populations at hatch (the largest body size of dace larvae and the smallest of the chub) were positively correlated to their eggs (Table 1) size and time of incubation (KUPREN et al. 2008a). These differences are

connected with different behavioural strategies of young fish during few first days of life (MANN 1996, KUPREN et al. 2008b).

The poor hatching percentage (< 50 %) and formation the highest level of malformed larvae at sublethal temperature (7.5 and 23.0°C for dace, 9.5 and 23.0°C for ide, 12.3 and 27.5°C for chub) suggest that this rearing temperature is well above the tolerance limit for development of their eggs or may be due to the lack of adequate enzymes involved in hatching (REDDY and LAM 1991). Higher hatching rate at others treatments suggest that these temperature ranges are most suitable for incubation.

Conclusions

Overall results suggest that 9.5–12.3°C, 15.7°C and 19–23.0°C are the optimal temperatures recommended for eggs incubation of dace, ide and chub, for better hatching percentage, lowest incidence of abnormalities, best developed larvae and harmonious embryonic development. These results also may help optimizing and reduced costs of production of stocking material. This study also reveals that embryos of studied species can adapt to increasing water temperature due to global warming up to 23.0°C (dace and ide) and 27.5°C (chub).

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