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EFFECTS OF STOCKING DENSITY AND WEANING AGE ON CANNIBALISM, SURVIVAL AND GROWTH IN EUROPEAN PERCH *PERCA FLUVIATILIS* LARVAE

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K e y w o r d s: cannibalism, European perch, growth, larvae, stocking density, survival, weaning age.

A b s t r a c t

The present study was designed to investigate the effects of stocking density and weaning age on growth, survival and cannibalism in Eurasian perch (*Perca fluviatilis*) larvae under controlled conditions. Two weeks experiment was conducted with 7 day post-hatch perch larvae (mean weight – 2.9 mg). Effects of two different stocking density (low 'L'- 13 and high 'H'- 26 larvae dcm^{-3}) and three weaning age treatments (7, 10 and 14 days post-hatching) on cannibalism, survival and growth in perch larvae under controlled conditions were evaluated. Type I (incomplete) cannibalism was significantly affected by weaning age but not by initial stocking density. The significantly lowest losses due to type I cannibalism were observed in both densities weaned at 14 dph and were 8.0 ± 0.5% and 8.6 ± 1.2% for low and high density, respectively. In other groups losses due to type I cannibalism exceeded 12% and did not differ significantly between stocking densities and other weaning age treatments. None of the factors had a significant impact on type II (complete) cannibalism. Survival and mortality other than cannibalism were significantly affected by both: stocking density and weaning age. The later weaning was found to impact positively on the survival of perch larvae, mainly through a reduction of cannibalism type I and mortality other than cannibalism. The significantly highest mean survival rate was obtained in both low (61.5 ± 2.1%) and high (57.0 ± 3.9%) density groups weaned at 14 dph. In other groups survival not exceeded 51% and did not differ significantly between stocking densities and other weaning age treatments. No significant effects of stocking density or weaning age on growth or size heterogeneity were found. The final body weight (FBW), growth rate (SGR) and coefficient of variation of FBW (CV_{FBW}) ranged from 0.025 ± 0.016 g to 0.032 ± 0.020 g, from 15.82 ± 0.42% day^{-1} to 17.16 ± 0.76% day^{-1}, and from 39.02 ± 3.32% to 48.58 ± 9.04%, respectively.

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TEMPO WZROSTU, PRZEŻYWALNOŚĆ I KANIBALIZM LARW OKONIA EUROPEJSKIEGO *PERCA FLUVIATILIS* (L.) W ZALEŻNOŚCI OD POCZĄTKOWEGO ZAGĘSZCZENIA OBSAD ORAZ CZASU PRZEJŚCIA NA ŻYWIENIE WYŁĄCZNIE PASZĄ KOMERCYJNĄ

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S ł o w a k l u c z o w e: kanibalizm, okoń europejski, larwy, tempo wzrostu, przeżywalność, wielkość obsady, przejście na żywienie paszą.

A b s t r a k t

Niniejsze badanie miało na celu zbadanie wpływu początkowego zagęszczenia i czasu przejścia na żywienie wyłącznie paszą komercyjną na przeżywalność, kanibalizm i tempo wzrostu larw okonia europejskiego (*Perca fluviatilis*) w warunkach kontrolowanych. Dwutygodniowy eksperyment przeprowadzono na 7 dniowych larwach okonia (średnia waga – 2,9 mg). Zastosowano sześć wariantów eksperymentalnych w zależności od początkowego zagęszczeniach (małego „L" – 13 i dużego „H"- 26 larw dcm^{-3}) i momentu przejścia na żywienie wyłącznie paszą (7, 10 i 14 dni po wykluciu). Na wzrost zachowań kanibalistycznych obserwowanych u larw okonia z dwóch badanych czynników istotnie wpływał tylko moment wyeliminowania z karmienia pokarmu żywego. Najniższe straty spowodowane tym typem kanibalizmu obserwowano w obu grupach ryb niezależnie od początkowego zagęszczenia obsady (odpowiednio 8.0 ± 0.5 i 8.6 ± 1.2% dla obsady L i H), których żywienie wyłącznie paszą komercyjną rozpoczęto najpóźniej tj. w 14 dniu po wykluciu. W pozostałych grupach straty spowodowane kanibalizmem typu I przekraczały 12% i nie różniły się w zależności od wielkości obsad oraz od zastosowanych wariatów żywieniowych. Zarówno czas przejścia na karmienie wyłącznie paszą, jak i zastosowane wielkości obsad nie wpłynęły znacząco na intensywność kanibalizmu typu II, miały natomiast istotny wpływ na końcową przeżywalność okoni oraz na obserwowaną śmiertelność nie spowodowaną kanibalizmem. Najwyższą przeżywalność obserwowano w grupach ryb, których żywienie wyłącznie paszą komercyjną rozpoczęto najpóźniej tj. w 14 dniu po wykluciu, niezależnie od początkowej wielkości obsady, która wyniosła odpowiednio 61.5 ± 2.1 i 57.0 ± 3.9% dla grup L i H. Zarówno początkowe zagęszczenie larw, jak i moment przejścia na żywienie okoni z wykorzystaniem wyłącznie paszy komercyjnej nie wpłynęły istotnie na końcowe parametry zootechniczne ryb. Średnia końcowa masa ryb (FBW), ich względne tempo wzrostu (SGR) oraz współczynnik zróżnicowania masy (CV_{FBW}) mieściły się odpowiednio w zakresach od 0.025 ± 0.016 g do 0.032 ± 0.020 g dla FBW, od 15.82 ± 0.42% $dzień^{-1}$ do 17.16 ± 0.76% $dzień^{-1}$ dla SGR oraz od 39.02 ± 3.32% do 48.58 ± 9.04% dla CV_{FBW}.

Introduction

European perch (*Perca fluviatilis*) is a strong candidate for percid fish species and product diversification in the European freshwater aquaculture due to its high flesh quality and high market value (KESTEMONT and MÉLARD 2000, LJUNGGREN et al. 2003, STEJSKAL et. al 2009). Aquaculture of perch has been developing rapidly in recent years with many new methods of reproduction (KUCHARCZYK et al. 1996; 1998, KOUŘIL et al. 1997, MIGUAD et al. 2004,

SZCZERBOWSKI et al. 2009, ŻARSKI et al. 2011a,b). The larval and juvenile production of perch has been recognized as one of the main bottlenecks in the industrial production of this species, mainly because of high cannibalism and mortality at weaning time (BRABAND 1995, BARAS et al. 2003, KESTEMONT et al. 2003, BABIAK et al. 2004).

The cannibalism occurs in many cultured fish species, including non-predatory species (VAN DAMME et al. 1999), however it is most prevalent in piscivorous taxa, especially at larval and juvenile stages (SMITH and REAY 1991, HECHT and PIENAAR 1993, BARAS and JOBLING 2002). In European percid larviculture, intra-cohort cannibalism is an important issue that can induce losses exceeding 50% of the initial density during the first weeks of rearing (BARAS et al. 2003, KESTEMONT et al. 2003, BABIAK et al. 2004, KESTEMONT et al. 2007, KRÓL et al. 2015, KRÓL and ZAKĘŚ 2015). During the first days of life, when the size heterogeneity of larvae is low, type I cannibalism (incomplete – biting the abdomen or tail) occurs. Later, as size dispersal of larvae increases, type I cannibalism is replaced by type II cannibalism (complete – total prey ingestion) (CUFF 1980, HECHT and APPELBAUM 1988, HECHT and PIENAAR 1993, BARAS and JOBLING 2002, BARAS et al. 2003). Nowadays, cannibalism is regarded as an alternative feeding strategy, influenced rather by environmental than genetic factors (HECHT and PIENAAR 1993, SVENNING and BORGSTRØM 2005, BARAS and LUCAS 2010, BARAS et al. 2014, KRÓL et al. 2014). BARAS and JOBLING (2002) identified several population factors, as well as extrinsic factors that regulate size heterogeneity and cannibalism in fish. The previous results indicate that in European perch larvae, increasing stocking density did not impair growth, but significantly decreased of losses due to cannibalism (BARAS et al. 2003, KESTEMONT et al. 2003).

Food availability and quality are the most important factors which can account for the emergence and intensity of cannibalism within a larvae cohort (HECHT and APPELBAUM 1988, KUBITZA and LOVSHIN 1999, HECHT and PIENAAR 1993, BARAS and JOBLING 2002, BARAS 2013). Feeding levels have a significant effect on survival of perch post-larvae with increasing impact of cannibalism at lower doses of food (FIOGBÉ and KESTEMONT 2003). The larvae of European percid fish species are very small and must be fed with live food first (KESTEMONT et al. 2007), however, relevant study has been demonstrated that pikeperch larvae can be successful reared with feeding by formulated feed only (OSTASZEWSKA et al. 2005). Furthermore it is rather important to wean larvae at the earliest possible stage of rearing in order to decrease the cost of production (BASKERVILLE-BRIDGES and KLING 2000, PALIŃSKA-ŻARSKA et al. 2014). Weaning is a critical step for all cultured fish as the transition from live food to commercial feed often results in high mortality (FLETCHER et al. 2007, POLICAR et al. 2007). Success of weaning is dependent on several factors such

as feed quality and feeding procedure (WOCHER et al. 2013) but also on correlation of time in substitution of live food by formulated diet with the development of the digestive system of the larvae (KESTEMONT et al. 1996, 2007). European percid fish larvae ingest dry food after yolk sac absorption so fish can be trained to accept and to use a dry diet efficiently starting at the end of maturation processes of the digestive system, both in terms of morphological structures and enzymatic activities (HAMZA et al. 2007).

Therefore, the present study was designed to investigate the effects of stocking density and weaning age on growth, survival and cannibalism in perch larvae under controlled conditions.

Material and Methods

Experimental larvae origin

Spawners were captured in Sasek Wielki Lake (North-Eastern Poland) in early April. Immediately after catching, the fish were transported to the recirculating aquaculture systems (RAS) in Aquaculture and Ecological Engineering Center, University of Warmia and Mazury in Olsztyn, Poland. The gametes of perch were obtained in accordance with the previously established procedure (ŻARSKI et al. 2011b). Egg-ribbons from two females were fertilized with pooled semen from four males. Eggs were incubated in a flow-through water recirculating system at 14°C. Just before hatching, ribbons were placed in 500 dcm^{-3} tank at 17°C. Larvae started to hatch on day 8 post fertilization. After 24 hours from the first hatching, ribbons with unhatched embryos were removed from the tank. Perch larvae were reared in the same tank for the next 6 days. Temperature was progressively increased to 21°C and dissolved oxygen was maintained to saturation at 9.5 mg dcm^{-3}. Before the experiment, larvae were co-fed with *Artemia* nauplii and dry diet in *ad libitum* from 3 days post-hatching (dph).

Experimental design, data collection and analysis

Two weeks experiment was conducted with 7 dph perch larvae (with swim bladder inflation – ISBI at 67%). Before the experiment, 30 perch larvae were sacrificed by using an overdose of anesthetic (2-phenoxyethanol – 2 $ml \cdot dcm^{-3}$) then individually weighed (nearest to 0.0001 g) and measured (nearest to 0.01 cm). ISBI (%) was estimated on observation of larvae using stereo microscope in terms of inflation or not their swim bladders. Six experimental groups with

two different stocking density (low 'L' – 13 and high 'H' – 26 larvae dcm^{-3}) and three weaning age treatments (7, 10 and 14 dph) were set in triplicates. Newly-hatched *Artemia* nauplii (AF ± 430 micron size, INVE, Belgium) were used as live preys. For co-feeding procedure, daily feeding level for live prey were 1.5 g and 3.0 g per aquarium for L and H stocking density, respectively. For co-feeding and weaning procedure, commercial diet (Aller ArtEX 2, Aller Aqua, Poland) containing 50% protein, 14% lipid and 22,5% carbohydrates was used. A daily feeding level for Aller ArtEX 2 increasing from 100% of fish initial biomass on day 1 to 200% of fish initial biomass on day 14. During the all experiment, larvae were fed by hand six times a day (8:00, 10:00, 12:00, 14:00, 17:00 and 20:00), in co-feeding time *Artemia* were added first, before commercial feed. The weaning ages were applied on days 7, 10 and 14 post-hatch in both stocking densities. The perch larvae were reared during 14 days in a recirculating aquaculture system consisting of 18 rectangle glass aquaria with a volume of 15 dcm^{-3} each. The recirculating system was equipped with UV lamp, a lamellar filter for mechanical water purification and a trickling filter for biological water purification. The daily water exchange amounted to 10% of the total unit volume (1.5 m^3). The water flow through the rearing aquaria was 1.5 dcm^{-3} min^{-1}. The fish were exposed to a 24 h light and 0 h dark photoperiod, and the light intensity measured just above the water surface in the rearing aquaria ranged from 60 to 80 lx. The water temperature and dissolved oxygen were measured daily and totaled, on average, 21.5 ± 0.5°C and 8.1 ± 0.7 mg l^{-1}, respectively. Nitrogenous compounds were measured semiweekly in rearing volume of water and did not exceed 0.15 and 0.07 mg dcm^{-3} for $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$, respectively. The rearing aquaria were cleaned of unconsumed food and fish waste once daily in the morning before feeding. Dead fish were removed daily and ranked as truncated (posterior damaged or tailed-off) or non-truncated (starving, intact, or with traces of bites on the abdomen or head) using Stereo Microscope LEICA MZ16A with Qwin Pro software. Truncated individuals were considered as victims of type I cannibalism and non-truncated fish as deaths by other causes. A bitten abdomen or head are typical secondary postmortem damages in cultured percids, therefore individuals having such damages were not classified as type I cannibalism victims (BARAS et al. 2003, BABIAK et al. 2004, KRÓL and ZAKĘŚ 2015).

At the end of the experiment all survivors per tank were counted and 30 fish per aquarium were weighed and measured. Other relevant parameters were assessed as a follows:

– Missing fish were considered as victims of type II cannibalism [(%) = 100 INF- (FNF + DF) INF^{-1}, where INF is initial number of fish, FNF is final number of fish, DF is number of truncated and non-truncated death fish].

– Coefficients of variation in body weight [CV(%) = $100 \cdot SDBW \cdot BW^{-1}$, where BW is average body weight and SDBW is standard deviation of body weight], were calculated for the first and last day of measurement (respectively, CV_{IBW} and CV_{FBW}).

– Overall specific growth rates [SGR (% day^{-1}) = $100 \cdot (Ln\ FBW - Ln\ IBW) \cdot t^{-1}$, where FBW is average final body weight and IBW is average initial body weight (g); t is14 days] were also calculated.

Statistical analysis

The data were analyzed using one-way ANOVA. The following validation of the normal distribution of the data, post hoc LSD Fisher test was used. Probability data in percentages were arcsine transformed before analysis. A two-way ANOVA was also used to test the effects of stocking density (13 and 26 larvae dcm^{-3}) and weaning age (7, 10 and 14 dph) and the interactions of both factors on survival, both types of cannibalism and other counted mortality. Differences were considered significant at $p<0.05$.

Results

Cannibalism and survival

The significantly highest mean survival rate was obtained in both low and high density groups weaned at 14 dph (Figure 1). Significant differences in survival between low and high stocking density groups were found at 7 dph weaning age, only (Figure 1). The significantly lowest losses due to type I cannibalism were observed in both densities weaned at 14 dph and were 8.0 ± 0.5 and 8.6 ± 1.2% for low and high density, respectively (Figure 2). In other groups losses due to type I cannibalism exceeded 12% and did not differ significantly between stocking densities and other weaning age treatments (Figure 2). Losses to type II cannibalism ranged from 12 to 21%, but did not differ significantly between treatments (Figure 3). The significantly lowest mortality other than cannibalism (15,5%) was found in group with low density weaned at 14 dph (Figure 4). The highest counted mortality values were observed in both densities weaned at 10 dph and were 24.5 ± 1.2% and 24.7 ± 0.3% for low and high density, respectively (Figure 4). Based on two-way ANOVA, survival was significantly affected by stocking density and weaning age at $p = 0.0191$ and $p = 0.0012$, respectively. Also mortality other than cannibalism was significantly affected by stocking density ($p = 0.0087$) and

weaning age (p = 0.0015). Cannibalism type I was significantly affected by weaning age (p = 0.0079) but not by initial stocking density (p>0.05). None of the factors had a significant impact on cannibalism type II (p>0.05). Significant interaction between the two parameters was found only in case of mortality other than cannibalism (p = 0.0169).

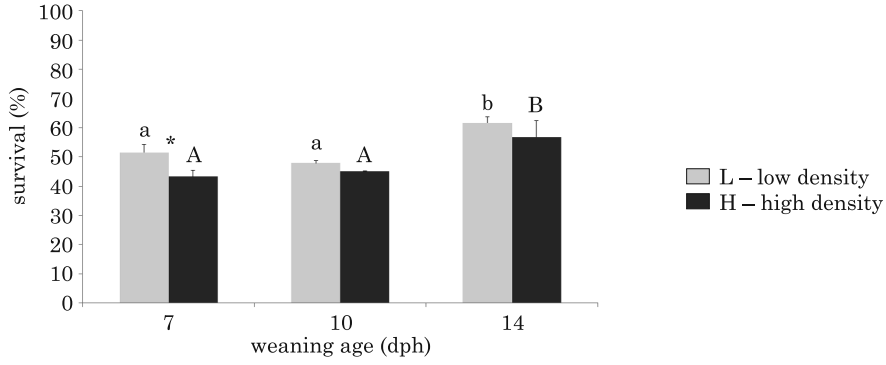

Fig. 1. Survival (mean ± SD) of perch larvae (22 dph) in relation to weaning age (7, 10 and 14 dph) and initial stocking density (L – 13 and H – 26 larvae dcm^{-3}). Lowercase letters indicate statistical differences among low density groups following different weaning age. Capital letters indicate differences among high density groups following different weaning age. Asterisks indicate significant differences between low and high density at the same weaning age (p<0.05)

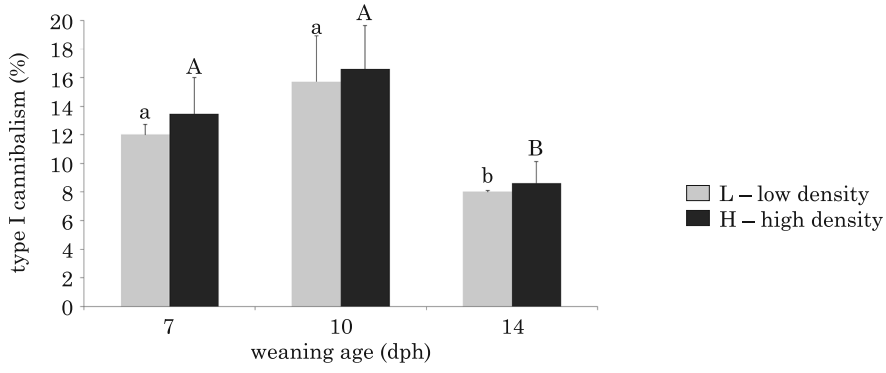

Fig. 2. Incomplete (type I) cannibalism (mean ± SD) of perch larvae in relation to weaning age (7, 10 and 14 dph) and initial stocking density (L – 13 and H – 26 larvae dcm^{-3}). Lowercase letters indicate statistical differences among low density groups following different weaning age. Capital letters indicate differences among high density groups following different weaning age (p<0.05). No significant differences between low and high density at the same weaning age were found (p>0.05)

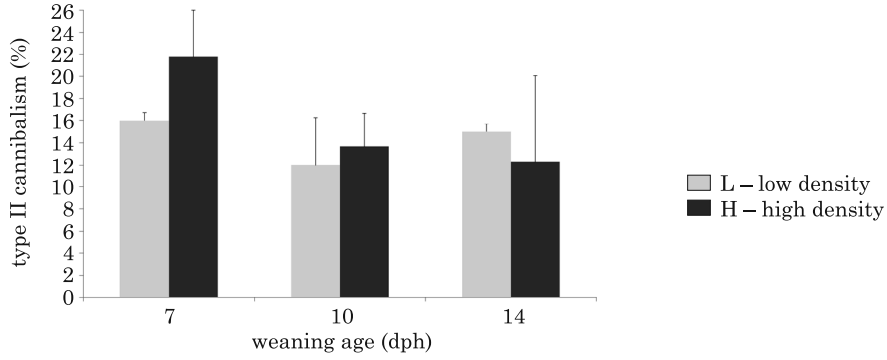

Fig. 3. Complete (type II) cannibalism (mean ± SD) of perch larvae in relation to weaning age (7, 10 and 14 dph) and initial stocking density (L – 13 and H – 26 larvae dcm^{-3}). No significant differences among treatments were found ($p>0.05$)

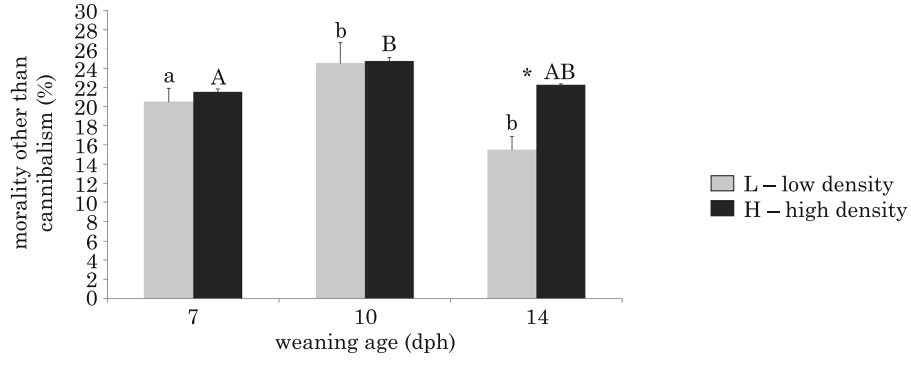

Fig. 4. Mortality other than cannibalism (mean ± SD) of perch larvae in relation to weaning age (7, 10 and 14 dph) and initial stocking density (L – 13 and H – 26 larvae dcm^{-3}). Lowercase letters indicate statistical differences among low density groups following different weaning age. Capital letters indicate differences among high density groups following different weaning age. Asterisks indicate statistically significant differences between low and high density at the same weaning age ($p<0.05$)

Growth performance

Mean of FBW and SGR did not differ among all experimental groups (Table 1). CV in weights increased by almost 2 times from the beginning (CV_{IBW}) to the end of the experiment (CV_{FBW}), but did not differ among all groups (Table 1).

Table 1. Mean values (±SD) of initial (n = 30 fish) and final (n = 3 replicates) parameters of perch larvae reared with two different stoking density (L – 13 and H – 26 larvae dcm^{-3}) and three weaning age treatments (7, 10 and 14 dph) during 14 days. No significant differences were found among treatments (One-way ANOVA, LSD post-hoc test, p>0.05)

Parameter	Group					
	L7	L10	L14	H7	H10	H14
Initial Body Weight (g) – IBW	0.0029 ± 0.0007					
Coefficient of variation of IBW (%) – CV_{IBW}	23.91					
Initial Swim Bladder Inflation (%) – ISBI	67					
Final Body Weight (g) – FBW	0.028 ± 0.012	0.028 ± 0.014	0.032 ± 0.020	0.025 ± 0.018	0.025 ± 0.016	0.031 ± 0.013
Coefficient of variation of FBW (%) – CV_{FBW}	41.40 ± 2.91	42.66 ± 2.03	48.58 ± 9.04	45.20 ± 0.50	41.66 ± 6.58	39.02 ± 3.32
Specific Growth Rate (% day^{-1}) – SGR	16.19 ± 0.33	16.17 ± 0.65	17.16 ± 0.76	15.82 ± 0.42	15.85 ± 0.30	16.80 ± 0.75

Discussion

In case of the European perch, rearing larvae at higher densities usually resulted in the better survival rate (BARAS et al. 2003, KESTEMONT et al. 2003), contrary to the pikeperch where growth and survival in the final phase of rearing decreased with increasing initial larval stocking density (SZKUDLAREK and ZAKĘŚ 2007). The higher rates of cannibalism at lower stocking densities can be accounted for the development of dominance hierarchies in perch larvae, resulted from available territories within a limited space, because in this species cannibalism is facilitated by territorial behavior (BRABAND 1995, MÉLARD et al. 1996). In contrast to the results obtained by the aforementioned studies, higher density did not result in reduction of cannibalistic behavior here, however both densities used in this study were lower than mentioned before, rather on experimental not industrial scale.

Beside several population factors as well as extrinsic factors that regulate cannibalism in fish larvae the quantity of feed, method of its providing and reducing frequency of feeding may enhance the intensity of cannibalism (HECHT and APPELBAUM 1988, HECHT and PIENAAR 1993, BARAS and JOBLING 2002, SZCZEPKOWSKI 2009, TRABELSI et al. 2011). Weaning is a critical rearing period for all fish species, and on several occasions, the supplementation of diet with live prey was found to reduce agonistic and cannibalistic behaviours (HECHT and PIENAAR, 1993). In both cultured, European percid species, several authors suggested that further studies are required for optimization of the weaning protocol at the earliest possible stage of larval rearing (KESTEMONT

et al. 2003, 2007, SZCZEPKOWSKI et al. 2011). Moreover, commercial feed has a higher energy content than live prey, and the determination of age at which perch larvae can be weaned is a pivotal, for reducing feeding costs. The results of our experiment for the first time indicate that procedure of weaning, preceded by co-feeding may significantly reduce cannibalism type I in perch larviculture. The later weaning was found to impact positively on the survival of perch larvae, mainly through a reduction of cannibalism type I and mortality other than cannibalism. That is probably due to the fact that perch larvae in late weaned groups had more time to the sudden change to an artificial diet. Our results are consistent with previous observations in other fish species, that co-feeding strategies can improve survival of fish larvae especially in early stages of their life (BASKERVILLE-BRIDGES and KLING 2000, LIU et al. 2012, LJUBOBRATOVIĆ et al 2015).

The our study confirmed that cannibalism is an important factor in European perch larviculture and a similar impact of both types of cannibalism may stem from a short duration of the experiment, usually type II cannibalism is more intense than the type I in long-lasting rearing (MANDIKI et al. 2007, KRÓL et al. 2015). The low difference between contributions of type I and type II cannibalism here can also resulted due to the fact that our study started with larvae with incomplete inflated swim bladder (67%) and thereby accelerated emergence of complete cannibalism. This occurs because European percid larvae with non-inflated swim bladders are easy victims for cannibals due to the impairment of motor skills (SZCZEPKOWSKI et al. 2011, KRÓL and ZAKĘŚ 2015). However, swim bladder inflation in pikeperch can occur on day 5 after hatching and can last until days 11 or 12 (DEMSKA-ZAKĘŚ et al. 2003), so it is conceivable that also some percent of perch larvae can inflated swim bladder in the first week of our experiment.

The effect of rearing strategy on larval growth is also an important parameter although it may not be as critical as survival, since larval size dispersal may be compensated at further rearing of fish, e.g.: high size variation of larvae can facilitate the emergence of cannibalism (BARAS and JOBLING 2002, KRÓL et al. 2015). Moreover, minimize growth heterogeneity in the cohort is a good aquaculture practice in order to minimize food wastage and water quality degradation (KESTEMONT et al. 2003). High initial stocking density of perch larvae does not adversely affect larval growth (MÉLARD et al. 1996 BARAS et al. 2003, KESTEMONT et al. 2003). Also no growth positive effects were observed in Eurasian perch larvae when *Artemia nauplii* were distributed over longer periods (KESTEMONT et al. 2003). In the present study, growth parameters of perch larvae were not significantly affected by either weaning age or initial stocking density. However, co-feeding procedure improved the nutritional status of larvae to avoid high size variation of larvae in other taxa (CURNOW et al. 2006, ALVES et al. 2006, ENGROLA et al. 2007).

In conclusion, the results of our experiment indicate that procedure of weaning, preceded by co-feeding may significantly enhance survival in perch larviculture *via* reducing the intensity of cannibalism type I within first weeks of rearing.

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References

Alves T.T., Cerqueira V.R., Brown J.A. 2006. *Early weaning of fat snook* (*Centropomus parallelus Poey 1864) larvae*. Aquaculture, 253: 334–342.

Babiak I., Mandiki S.N.M., Ratsinjomanana K., Kestemont P. 2004. *Initial weight and its variation in post-larval Eurasian perch affect quantitative characteristics of juvenile cohorts under controlled conditions*. Aquaculture, 243: 263–276.

Baras E. 2013. *Cannibalism in fish larvae: What have we learned*? [In:] Qin J.G. (Ed) *Larval Fish Aquaculture*. Nova Science Publishers, New York.

Baras E., Hafsaridewi R., Slembrouck J., Priyadi A., Moreau Y., Pouyaud L. 2014. *Do cannibalistic fish possess an intrinsic higher growth capacity than others? A case study in the Asian redtail catfish Hemibagrus nemurus* (*Valenciennes*, 1840). Aquac. Res., 45: 68–79.

Baras E., Jobling M. 2002. *Dynamics of intracohort cannibalism in cultured fish*. Aquac. Res., 33: 461–479.

Baras E., Kestemont P., Mélard C. 2003. *Effect of stocking density on the dynamics of cannibalism in sibling larvae of Perca fluviatilis under controlled conditions*. Aquaculture, 219: 241–255.

Baras E., Lucas M.C. 2010. *Individual growth trajectories of sibling Brycon moorei raised in isolation since egg stage, and their relationship with aggressive behaviour*. J. Fish Biol., 77: 985–997.

Baskerville-Bridges B., Kling L.J. 2000. *Early weaning of Atlantic cod (Gadus morhua) larvae onto a microparticulate diet*. Aquaculture, 189: 109–117.

Braband A. 1995. *Intra-cohort cannibalism among larval stages of perch (Perca fluviatilis).* Ecol. Freshw. Fish, 4: 70–76.

Cuff W.R. 1980. *Behavioral aspects of cannibalism in larval walleye*, *Stizostedion vitreum*. Can. J. Zool., 58: 1504–1507.

Curnow J., King J., Bosmans J., Kolkovski S. 2006. *The effect of reduced Artemia and rotifer use facilitated by a new microdiet in the rearing of barramundi Lates calcarifer (BLOCH) larvae*. Aquaculture, 257: 204–213.

van Damme P., Appelbaum S., Hecht T. 1989. *Sibling cannibalism in Koi carp, Cyprinus carpio L., larvae and juveniles reared under controlled conditions*. J. Fish Biol., 34: 855–863.

Demska-Zakęś K., Kowalska A., Zakęś Z. 2003. *The development of the swim bladder of pikeperch Sander lucioperca (L.) reared in intensive culture*. Arch. Pol. Fish., 11: 45–55.

Engrola S., Conceição L.E.C., Dias L., Pereira R., Ribeiro L., Dinis M.T. 2007. *Improving weaning strategies for Senegalese sole: effects of body weight and digestive capacity*. Aquac. Res., 38: 696–707.

Fiogbé E.D., Kestemont P. 2003. *Optimum daily ration for Eurasian perch Perca fluviatilis L. reared at its optimum growing temperature*. Aquaculture, 216: 243–252.

Fletcher R.C., Roy W., Davie A., Taylor J., Robertson D., Migaud H. 2007. *Evaluation of new microparticulate diets for early weaning of Atlantic cod (Gadus morhua): implications on larval performances and tank hygiene*. Aquaculture, 263: 35–51.

Hamza N., Mhetli M., Kestemont P. 2007. *Effects of weaning age and diets on ontogeny of digestive activities and structures of pikeperch (Sander lucioperca) larvae*. Fish Physiol. Biochem., 33:121–133.

Hecht T., Appelbaum S. 1988. *Observations on intraspecific aggression and coeval sibling cannibalism by larval and juvenile Clarias gariepinus (Clariidae: Pisces) under controlled conditions*. J. Zool., 214: 21–44.

Hecht T., Pienaar G.A. 1993. *A review of cannibalism and its implications in fish larviculture*. J. World Aquacult. Soc., 24: 246–261.

Kestemont P., Jourdan S., Houbart M., Mélard C., Paspatis M., Fontaine P., Cuvier A., Kentouri M., Baras E. 2003. *Size heterogeneity, cannibalism and competition in cultured predatory fish larvae: biotic and abiotic influences*. Aquaculture, 227: 333–356.

Kestemont P., Mélard C. 2000. *Aquaculture*. [In:] Craig J.F. (Ed) *Percid Fishes – Systematics, Ecology and Exploitation*. Wiley-Blackwell, Oxford.

Kestemont P., Mélard C., Fiogbé E., Vlavaonou R., Masson G. 1996. *Nutritional and animal husbandry aspects of rearing early life stages of Eurasian perch Perca fluviatilis*. J. Appl. Ichthyol., 12: 157–165.

Kestemont P., Xueliang X., Hamza N., Maboudou J., Imorou Toko I. 2007. *Effect of weaning age and diet on pikeperch larviculture*. Aquaculture, 264: 197–204.

Kouřil J., Linhart O., Reiot P. 1997. *Induced spawning of perch by means of a GnRH analogue*. Aquacult. Int., 5: 375–377.

Król J., Dauchot N., Mandiki S.N.M., van Cutsem P., Kestemont P. 2015. *Cannibalism in cultured Eurasian perch Perca fluviatilis (Actinopterygii: Perciformes: Percidae) – implication of maternal influence, kinship and sex ratio of progenies*. Acta Ichthyol. Piscat., 45: 65–73.

Król J., Flisiak W., Urbanowicz P., Ulikowski D. 2014. *Growth, cannibalism, and survival relations in larvae of European catfish, Silurus glanis (Actinopterygii: Siluriformes: Siluridae) – attempts to mitigate sibling cannibalism*. Acta Ichthyol. Piscat., 44: 191–199.

Król J., Zakęś Z. 2015. *Effect of dietary L-tryptophan on cannibalism, survival and growth in pikeperch Sander lucioperca (L.) post-larvae*. Aquacult. Int., (in press), DOI: 10.1007/s10499-015-9936-1.

Kucharczyk D., Kujawa R., Mamcarz A., Skrzypczak A., Wyszomirska E. 1996. *Induced spawning in perch, Perca fluviatilis L. using carp pituitary extract and HCG*. Aquac. Res., 27: 847–852.

Kucharczyk D., Kujawa R., Mamcarz A., Skrzypczak A., Wyszomirska E. 1998. *Induced spawning in perch, Perca fluviatilis L., using FSH or LH with pimozide or metoclopramide*. Aquac. Res., 29:131–136.

Kubitza F., Lovshin L.L. 1999. *Formulated diets, feeding strategies and cannibalism during intensive culture of juvenile carnivorous fishes*. Rev. Fish. Sci., 7: 1–22.

Liu B., Zhu X., Lei W., Yang Y., Han D., Jin J., Xie S. 2012. *Effects of different weaning strategies on survival and growth in Chinese longsnout catfish (Leiocassis longirostris Gunther) larvae*. Aquaculture, 364–365: 13–18.

Ljubobratović U., Kucska B., Feledi T., Poleksić V., Marković Z., Lenhardt M., Peteri A., Kumar S., Rónyai A. 2015. *Effect of weaning strategies on growth and survival of pikeperch, Sander lucioperca, larvae*. Turk. J. Fish. Aquat. Sc., 15: 327–333.

Ljunggren L., Staffan F., Falk S., Linden B., Mendes J. 2003. *Weaning of juvenile pikeperch, Stizostedion lucioperca L., and perch, Perca fluviatilis L., to formulated feed*. Aquac. Res., 34: 281–287.

Mandiki S.N.M., Babiak I., Krol J., Rasolo J.F.R., Kestemont P. 2007. *How initial predator-prey ratio affects intra-cohort cannibalism and growth in Eurasian perch Perca fluviatis L larvae and juveniles under controlled conditions*. Aquaculture, 268: 149–155.

Mélard C., Baras E., Mary L., Kestemont P. 1996. *Relationships between stocking density, growth, cannibalism and survival rate in intensively cultured larvae and juveniles of perch (Perca fluviatilis)*. Ann. Zool. Fennici, 33: 643–651.

MIGUAD H., GARDEUR J.N., KESTEMONT P., FONTAINE P. 2004. *Off-season spawning of Eurasian perch Perca fluviatilis*. Aquacult. Int., 12: 87–102.

OSTASZEWSKA T., DABROWSKI K., CZUMINSKA K., OLECH W., OLEJNICZAK M. 2005. *Rearing of pike-perch larvae using formulated diets – first success with starter feeds*. Aquac. Res. 36: 1167–1176.

PALIŃSKA-ŻARSKA K., ŻARSKI D., KREJSZEFF S., NOWOSAD J., BIŁAS M., TREJCHEL K., BRYLEWSKI A., TARGOŃSKA K., KUCHARCZYK D. 2014. *The effect of age, size and digestive tract development on burbot, Lota lota (L.) larvae weaning effectiveness*. Aquacult. Nutr., 20: 281–290.

POLICAR T., KOZÁK P., HAMÁCKOVÁ J., LEPICOVÁ A., MUSIL J., KOURIL J. 2007. *Effects of short-time Artemia spp. feeding in larvae and different rearing environments in juveniles of common barbel (Barbus barbus) on their growth and survival under intensive controlled conditions*. Aquat. Liv. Res., 20: 175–183.

SMITH C., REAY P. 1991. *Cannibalism of teleost fishes*. Rev. Fish Biol. Fish., 1: 41–64.

STEJSKAL V., KOUŘIL J., MUSIL J., HAMÁČKOVA J., POLICAR T. 2009. *Growth pattern of all-female perch (Perca fluviatilis L.) juveniles – is monosex perch culture beneficial*? J. Appl. Ichthyol., 25: 432–437.

SVENNING M.A., BORGSTRØM R. 2005. *Cannibalism in Arctic charr: do all individuals have the same propensity to be cannibals*? J. Fish Biol., 66: 957–965.

SZCZEPKOWSKI M. 2009. *Impact of selected abiotic and biotic factors on the results of rearing juvenile stages of northern pike Esox lucius L. in recirculating systems*. Arch. Pol. Fish., 17: 107–147.

SZCZEPKOWSKI M., ZAKĘŚ Z., SZCZEPKOWSKA B., PIOTROWSKA I. 2011. *Effect of size sorting on the survival, growth and cannibalism in pikeperch (Sander lucioperca L.) larvae during intensive culture in RAS*. Czech J. Anim. Sci., 56: 483–489.

SZCZERBOWSKI A., KUCHARCZYK D., MAMCARZ A., ŁUCZYŃSKI M.J., TARGOŃSKA K., KUJAWA R. 2009. *Artificial off-season spawning of Eurasian perch Perca fluviatilis L.* Arch. Pol. Fish., 17: 95–98.

SZKUDLAREK M., ZAKĘŚ Z. 2007. *Effect of stocking density on survival and growth performance of pikeperch, Sander lucioperca (L.), larvae under controlled conditions*. Aquacult. Int., 15: 67–81

WOCHER H., HARSANYI A., SCHWARZ J.F. 2013. *Larviculture of burbot (Lota lota L.): larval rearing using Artemia and weaning onto dry feed*., Aquac. Res. 43: 1–8.

ŻARSKI D., BOKOR Z., KOTRIK L., URBANYI B., HORVATH A., TARGOŃSKA K., KREJSZEFF S., PALIŃSKA K., KUCHARCZYK D. 2011a. *A new classification of a pre-ovulatory oocyte maturation stage suitable for the synchronization of ovulation in controlled reproduction of Eurasian perch, Perca fluviatilis L.* Rep. Biol., 11: 194–209.

ŻARSKI D., PALIŃSKA K., TARGOŃSKA K., BOKOR Z., KOTRIK L., KREJSZEFF S., KUPREN K., HORVATH A., URBANYI B., KUCHARCZYK D. 2011b. *Oocyte quality indicators in Eurasian perch, Perca fluviatilis L., during reproduction under controlled conditions*. Aquaculture, 313: 84–91.