Effect of stocking density on growth, survival and development of asp Aspius aspius (L.), ide Leuciscus idus (L.) and chub Leuciscus cephalus (L.) larvae during initial rearing under laboratory conditions

Krzysztof Kupren, Daniel Żarski, Sławomir Krejszeff, Dariusz Kucharczyk, Katarzyna Targoń

Department of Lake and River Fisheries, University of Warmia and Mazury in Olsztyn, Poland

Abstract

This study was aimed at determining the effect of stocking density on growth, survival and development of asp Aspius aspius (L.), ide Leuciscus idus (L.) and chub Leuciscus cephalus (L.) larvae, reared under laboratory conditions. Fish larvae were obtained during artificial reproduction. The larvae were fed ad libitum with freshly hatched Artemia sp. nauplii. Eight density variants from 50 to 400 individuals per 1 L (at the interval of 50 individuals L⁻¹) were tested. The initial rearing was carried out for 21 days at 25°C in a recirculation system especially designed for that purpose consisting of 16 tanks with a capacity of 1 L each. The fastest growth rate for all three species, expressed as the greatest average total length, weight and most advanced ontogenetic stage at the end of the experiment, was obtained at the lowest stocking density. Fish from other treatments, particularly at densities exceeding 150 individuals L⁻¹, were characterized by similar body sizes and the same ontogenetic stage on the last day of rearing. The recorded differences in the length of larvae among treatments became visible during the first (asp) or third (chub, ide) week of rearing. No effects of stocking density on larval mortality were found during the experiment.

Introduction

As a consequence of the evident population decline of riverine cyprinid fishes, resulting from environmental degradation (Saunders et al., 2002; Witkowski et al., 2004), several species have recently been the object of restoration aquaculture (Kamel et al., 1998; Kujawa et al., 1998; 1999; Shiri Harzevili et al., 2003; 2004; Targoriska-Dietrich et al., 2004; Krejszeff et al., 2008; 2009; Kupren et al., 2009; Hamáčková et al., 2009; Kupren et al. 2011, Mamcarz et al. 2011). Consideration of various aspects of reproduction, as well as improvement of incubation methods and rearing techniques have significantly increased the current level of production of many species in Poland since the late 1990s (Kucharczyk et al., 1997a; 1997b; 2007; 2008a; Babiak et al., 1998, Kujawa et al., 1998 Lahnsteiner et al., 2000; 2003; Jamróz et al., 2008; Cezko et al., 2010). Asp Aspius aspius (L.), ide Leuciscus idus (L) and chub Leuciscus cephalus (L.) are cyprinid species characteristic of almost all rivers in Europe (Mamcarz, 2008). Together with other rheophilic cyprinids, these three species are not an object of commercial exploitation or aquaculture; they owe their economic importance mainly to angling (Turkowski et al., 2008b). Asp and chub have large potential as species used for biomanipulation aimed at reduction of the overpopulated species in rivers (Donabaum et al., 1999). Embryos and larvae of the studied species, are also potential objects of various laboratory tests (Gemulka et al., 2011).

Production of fish is more and more frequently conducted in recirculation systems, the profitability of which increases with technological development (Alvarez Gonzales et al., 2001; Turkowski et al., 2008a; Kupren et al., 2008c). In the case of intensive rearing of larvae, population density is one of the key factors influencing the effectiveness of rearing, particularly when water recirculation systems are used. Optimum stocking densities differ not only for individual species but also depending on the rearing method (Tucker, 1998; Papoutsoglou et al., 1998; Kwaśniewski et al., 2008). Stocking density has been shown to influence the survival and growth of larvae and a number of studies indicate the existence of a negative correlation between growth rate and stocking density (Irwin et al., 1999; Alvarez Gonzales et al., 2001; Imorou Toko et al., 2008; Żarski et al., 2008). In freshwater cyprinids, initial rearing under controlled conditions rarely exceeded stocking densities of 100 individuals per 1 L (Albrecht et al., 1977; Kujawa et al., 1998; Wolnicki and Myszkowski, 1999; Kujawa, 2004; Wolnicki, 2005; Shiri Harzevili et al., 2003; 2004; Policar et al., 2007; Hamáčková et al., 2009). Determining the optimum stocking density and its impact on larvae based on previous studies is rather difficult because of inconsistent feeding regimes (food type, quantity, and feeding frequency), different rearing temperatures and different photoperiod (Wolnicki, 2005). However, recent studies indicate that the density applied in the rearing of asp and chub larvae (Żarski et al., 2008) can exceed 100 individuals L⁻¹ without any negative effect on survival or growth rate. This study is aimed at determining the effects of stocking densities on growth rate, survival and development of the larvae of three species of rheophilic fish (ide, asp, and chub) during initial rearing under laboratory conditions.

Materials and methods

Origin of spawners, artificial reproduction and incubation

Fish larvae were obtained from three species, ide, asp and chub from controlled mass reproduction conducted at the hatchery of the Department of Lake and River Fisheries of the University of Warmia and Mazury in Olsztyn, Poland. The asp spawners (10 females and 12 males with body weight of 2000-5000 g)
The maximum fish load was 25 kg m\(^{-3}\). The dis-
solution oxygen level was over 6 ppm.

Table 1. Initial and final characteristics of reared asp *A. aspius* (Aa), ide *L. idus* (Li) and chub *L. cephalus* (Lc) (mean ± SD).

| Parameter                      | Stocking density, indic. L\(^{-1}\) |
|--------------------------------|-------------------------------------|
|                                | 50                                   |
| Mean initial length, mm Aa     | 9.60±0.35\(^{a}\)                    |
| Mean final length, mm Aa       | 25.03±0.26\(^{b}\)                   |
| Mean initial weight, mg Aa      | 3.15±0.18\(^{a}\)                    |
| Mean final weight, mg Aa        | 111.88±5.79\(^{a}\)                  |
| Survival, % Aa                  | 96.0±2.0\(^{a}\)                     |
| Specific growth rate, % d\(^{-1}\) Aa | 17.00±0.25\(^{a}\)                  |
| Mean initial length, mm Li      | 8.57±0.23\(^{a}\)                    |
| Mean final length, mm Li        | 24.15±0.78\(^{a}\)                   |
| Mean initial weight, mg Li      | 1.67±0.32\(^{a}\)                    |
| Mean final weight, mg Li        | 108.09±3.49\(^{a}\)                  |
| Survival, % Li                  | 89.8±1.0\(^{a}\)                     |
| Specific growth rate, % d\(^{-1}\) Li | 19.86±0.15\(^{a}\)                  |
| Mean initial length, mm Lc      | 7.76±0.21\(^{a}\)                    |
| Mean final length, mm Lc        | 23.33±0.25\(^{a}\)                   |
| Mean initial weight, mg Lc      | 1.25±0.26\(^{a}\)                    |
| Mean final weight, mg Lc        | 91.96±3.76\(^{a}\)                   |
| Survival, % Lc                  | 88.6±2.0\(^{a}\)                     |
| Specific growth rate, % d\(^{-1}\) Lc | 20.44±0.51\(^{a}\)                  |

Rearing techniques

The rearing of the larvae was carried out in a customized system consisting of one large glass 50 L tank functioning as a water bath with 16 smaller 1 L tanks partially submerged in it. The bath was equipped with a control-

able heater for adjusting water temperature with an accuracy of ±0.1°C, fluorescent lighting and an aeration system. To ensure the most effective exchange of water and prevent food leakage in each of the small tanks, one of the walls (2/3 of surface) was substituted with fine (200 μm) mesh. Additionally, each of the small tanks was equipped with regulated top inlet for filtered water. Biological and mechanical filtration for the entire system was provided by an external filter (Fluval 405, Hagen Inc., Montreal, Canada). This system was described in detail by Krejszeff et al. (2010). Sixteen experimental tanks were stocked at eight lar-
val densities: 50, 100, 150, 200, 250, 300, 350 and 400 individuals per 1 L with two replicates per treatment (a and b). Experiments began in the final stages of the absorption of the yolk sac (approximately 4\(^{th}\) day post-hatch) and it ended after 21 days of rearing. The larvae were fed 3 times a day (8.00; 12.00 and 16.00) *ad libitum* with live Artemia franciscana nauplii (San Francisco Bay Brand, Inc., Newark, CA, USA). The feed dose was proportional to the number of larvae in individual tanks. In all tanks, uneaten nauplii were present during illumination time. This was done to ensure that the quantity of food was not a limiting fac-
tor in this experiment. Three experiments (one for each species) were carried out in fol-
lowing trials in the same rearing system.

Flow rates were constant in all small tanks. High water flow (8 L h\(^{-1}\)) rates were utilized through the feeding trial to maintain stable water quality parameters. The dissolved oxy-
gen content did not drop below 80% saturation and pH ranged between 7.9 and 8.5 (measured with an HI 9828 multi-parameter instrument, Hanna Instruments, Vilafranca Padovana, PD, Italy). No effect of the eight densities was found on ammonia and nitrite concentrations when a continuous water flow was maintained through the tanks. The contents of ammonia and nitrites were less than 0.1 and 0.015 mg respectively (monitored with an LF 250 photometer, Slandi, Michalowice, Poland). Water temperature during rearing was constant at 25°C (±0.1°C). The water temperature was measured three times daily. Other water parameters were measured three times weekly in each experimental tank. The photoperiod was set at 12L:12D (light from 08.00 to 20.00 h). Every morning prior to feeding the aquaria were cleaned (dead fish were counted and removed) and 30% of the water was replaced with fresh water at the same temperature.

Sampling and analysis of samples

Random samples of 15 larvae per tank (30 per density) were taken every 7 d. Prior to the measurements, the fish were anesthetized in a solution of 2-phenoxyethanol (0.4 mL L\(^{-1}\);
Sigma-Aldrich, Germany) and were placed on Petri dishes (still in water). Larvae were measured (±0.01 mm) from a digitized image (DP-Soft software) captured with an optical microscope (Olympus, Tokio, Japan). This method reduced the total time of handling to 3 min. During the length measurement, fish development was also determined (larval and juvenile developmental step: L4-J1) according to Peňaž et al. (1983). The larvae after manipulation were transferred back to the tanks from which they were collected. The weight of individuals (±0.01 mg) was determined only at the beginning and at the end of the experiment in order to reduce larval mortality due to handling.

Daily specific growth rates were calculated for each treatment from the beginning of exogenous feeding through day 21, according to the following formula:

\[
\text{Specific growth rate (SGR; % day}^{-1} \text{)} = 100 \left( \frac{\ln BW_f - \ln BW_i}{T} \right)
\]

where \(BW_i/BW_f\) is the initial and final average larval body wet weight (±0.01 mg), and \(T\) is the duration of the experiment (days). Survival was evaluated by making daily counts of dead larvae collected from the bottom of the tanks by siphoning.

**Statistical analysis**

The statistical analysis of the data was carried out using the STATISTICA for Windows ver. 8.0 PL software package (StatSoft). The data are presented as means ± standard deviation (two replicates per treatment). All of the values expressed as percentages were arcsine transformed prior to statistical analysis. Differences between groups regarding larval length, weight, survival and SGR were analyzed with analysis of variance (ANOVA) and Tukey’s post-hoc test (\(\alpha=0.05\)). The comparison of the developmental stages between experimental groups was done using non-parametric Kruskal-Wallis ANOVA (\(\alpha=0.05\)).

**Results**

**Effects of stocking density on survival and growth**

Final survival rates of asp, ide and chub larvae were very high and similar in all the experimental groups, ranging from 93.3-96.3%, 88.7-95.5 and 82.0-88.6, respectively (Table 1). Observed mortality was recorded during the initial two weeks of rearing with the highest losses during the initial 7 days of the experiment (Figure 1). Significant differences (\(P<0.05\)) between groups in the average total length of the fish were observed after the first (asp), or third (ide, chub) week of rearing (Figure 2). In all species, stocking density affected (\(P<0.05\)) the final length and weight significantly. Fish mean length and weight showed a decreasing tendency with increasing stocking density. Fish reared at the lowest densities (50 larvae L\(^{-1}\)) had the highest mean final body length and weight (\(P<0.05\)) (asp: 25.03 mm, 111.89 mg; ide: 24.15 mm, 108.09 mg; chub: 22.68 mm and 91.96 mg). The sizes of fish originating from the other groups were similar and in the majority of cases (especially in densities above 150 larvae L\(^{-1}\)) did not show significant differences. At the end of the experiment their total length was within the range of 20.04-21.66 mm (asp), 19.68-20.75 (ide), 18.91-20.85 and their weight was within 44.42-62.37 mg (asp), 48.68-67.74 mg (ide), 43.98-65.31 mg (chub). A similar tendency was observed for

![Figure 1. Cumulative mortality of larval asp Aspius aspius (Aa), ide Leuciscus idus (Li) and chub Leuciscus cephalus (Lc) during rearing under laboratory conditions.](image-url)
specific growth rate. Daily SGRs ranged from 12.59 to 17.00 in asp, 16.06 to 19.87 in ide and 16.93 to 20.44 in chub (Table 1).

Effect of stocking density on development

Similar results to those of growth were obtained regarding the ontogenetic development (Table 2). The fastest development was observed in asp, ide and chub from the lowest stocking density (50 larvae L⁻¹). At the end of the experiment, only the lowest stocking density showed more than half of the individuals completing the larval period (stage = 6.7). In all fish smaller than 23.00 mm (TL) an embryonic finfold was still present in the anal part of body (between the pelvic and anal fins). Its size was inversely proportional to the size of the larvae (Table 2). The differences in the ontogenetic development between the larvae of each species were most evident during the first week of rearing (Table 2). On day 7 of the experiment the asp, the largest at that time, developed the best (stage L5, average 5.0) and the chub were the worst developed (stage L4 a-b average 4.2-4.4). The ontogenetic stage of ide at that time was determined for stage L4-L5 (average 4.6-4.8) (Table 2).

Discussion

Many different factors such as dissolved oxygen content, temperature, food quality or feeding regime might influence the cyprinid larval survival, growth and development (Kucharczyk et al., 1997c; 1998; Kujawa et al., 1997; Celada et al., 2007; Kwiatkowski et al., 2008; Zarski et al., 2008; Hamáčková et al., 2009; Kupren et al., 2011). The experimental system applied in this study provides stable, high quality water throughout the entire rearing period at all densities, which allows a proper analysis of the influence of variable density on larval growth and survival.

The obtained results clearly show that high stocking densities had no significant effect on the survival of asp, ide and chub larvae. High survival in all treatments suggests that high density aquaculture may be suitable for the production of these rheophilic species. The total mortality curves were similar for all the species and were independent of the applied densities. Increased mortality during the initial days of rearing is a common phenomenon among various fish species. The reasons for this observance are varied, but are usually linked to the difficulties in controlling water quality, change of feed, diseases and/or problems with inflation of the swim bladder (Alvarez-Gonzalez et al. 2001; Hatzianasniou et al., 2002; Foss et al., 2003; Szkudlarek and Zak 2007; Imorou Toko et al., 2008). In the case of the species used in this study, high mortality recorded during the initial days of rearing.

Table 2. Ontogenetic stage in asp A. aspius (Aa), ide L. idus (Li) and chub L. cephalus (Lc) larvae, recorded at the end of each week of rearing.

| Stocking density, indiv. L⁻¹ | 1 day | 7 day | 14 day | 21 day |
|-----------------------------|-------|-------|--------|--------|
|                             | Min   | Max   | Average | SD    | Min   | Max   | Average | SD    | Min   | Max   | Average | SD    |
| 50                          | 4     | 4     | 4.0a   | 0     | 5     | 5     | 5.0a    | 0     | 6     | 6     | 6.0a    | 0     |
| 100                         | 4     | 4     | 4.0a   | 0     | 5     | 5     | 5.0a    | 0     | 5.5   | 6     | 6.0a    | 0.1   |
| 150                         | 4     | 4     | 4.0a   | 0     | 4.5   | 5     | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 200                         | 4     | 4     | 4.0a   | 0     | 4.5   | 5     | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 250                         | 4     | 4     | 4.0a   | 0     | 4.5   | 5     | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 300                         | 4     | 4     | 4.0a   | 0     | 4.5   | 5     | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 350                         | 4     | 4     | 4.0a   | 0     | 4.5   | 5     | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 400                         | 4     | 4     | 4.0a   | 0     | 4.5   | 5     | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 50                          | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 100                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 150                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 200                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 250                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 300                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 350                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 400                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 50                          | 4     | 4     | 4.0a   | 0     | 4     | 5     | 4.8   | 0.4   | 5.5   | 6     | 6.0a    | 0.2   |
| 100                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 150                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 200                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 250                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 300                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 350                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |
| 400                         | 4     | 4     | 4.0a   | 0     | 4     | 4.8   | 5.0a    | 0.2   | 5.5   | 6     | 6.0a    | 0.2   |

DS, developmental step after Perkáč et al., 1983: larval step (DS 4, 4.0; DS 4b, 4.5; DS 5, 5.0; DS 5b, 5.5; DS 6, 6.0) and first juvenile step (DS 7, 7.0 = finfold disappeared); a-b different letters in the same column represent significant difference (P<0.05) between treatments.
life was probably linked to the mortality of larvae with developmental abnormalities, that did not start to intake exogenous food. Daily observations of dead fish showed that most of them had empty stomachs even if plenty of food had been added during daylight. Similar observations were made by Kujawa (2004), Kwiatkowski et al. (2008) and Żarski et al. (2008) who used the same kind of food. Our results and the results from other studies (Shiri Harzevilii et al., 2003; 2004; Kujawa 2004; Kwiatkowski et al., 2008) indicate that the asp, ide and chub larvae are able to ingest and digest Artemia nauplii from the onset of the exogenous feeding. In spite of the fact that while rearing chub the phenomenon of cannibalism has been observed (Żarski et al., 2008), it should be pointed out that in this study no species mortality caused by cannibalism was observed, which could also indicate favorable nutritional conditions during the process of rearing (Baskerville-Bridges and Kling 2000; Baras et al., 2003). Optimal conditions maintained in the small tanks used in this study allowed significantly reduced level of mortality in relation to cultures conducted in not fully-adopted units (Żarski et al., 2008; Kwiatkowski et al., 2008).

While no effect of density on mortality was found, in the case of growth rate of the larvae the influence of that factor was noticeable. At the end of the experiment the average final lengths and weights of the larvae, and also growth rates for all the species studied were largest in the groups with the lowest density (50 per L). Similar observations during rearing of those species were shown by Kujawa (2004) and Żarski et al. (2008). Additionally, the same correlation was frequently observed during the rearing of other numerous species (Irwin et al., 1999; Alvarez Gonzales et al., 2001; Imorou Toko et al., 2008; Kupren et al., 2008a). In the case of other density variants (>50 individuals per 1 L) both the average length, weight and the final development of the larvae of the three species studied were highly similar. In particular, the fish reared at densities of 150-400 individuals per 1 L in the majority of were cases characterized by the absence of significant differences in growth rate and ontogenetic stage. In the case of marine fish species such as the European sea bass Dicentrarchus labrax (L.) (Hatzianastasiou et al., 2002), Atlantic cod Gadus morhua (L.) (Baskerville-Bridges and Kling, 2000), and freshwater tench Tinca tinca (L.) (Celada et al., 2007), high densities reaching 320 individuals per L applied in the process of rearing were not the factors limiting growth. The absence of significant differences between each treatment in the rearing of the above listed species of marine fish species and tench undoubtedly resulted from securing a favorable rearing environment; particularly an excess of food. It could also be the result of the relatively small initial and final larval length (<13 mm) of those species. In the case of rearing asp, ide and chub, the significant differences in length between treatments started to appear when the fish reached ca. 15 mm in total length. The sizes of the larvae coupled with their relatively large numbers per volume unit could result in unfavorable social interactions (e.g. stress) influencing the diversification of growth rates between treatments at the end of the experiment (Bolesina et al., 2006; Rafatnezhad et al., 2008).

The analysis of SGR values showed that the fastest growth rate in all treatments were achieved by chub, which was the smallest in the beginning of exogenous feeding (7.76 mm, 1.25 mg) and the slowest growth rates were seen in asp, which were the largest fish at the beginning of exogenous feeding (9.60 mm, 3.15 mg) (Table 1). The larvae of smaller ini-

---

**Figure 2.** Mean (±SD) length of larval asp *Aspius aspius* (Aa), ide *Leuciscus idus* (Li) and chub *Leuciscus cephalus* (Lc) during rearing under laboratory conditions. Data with the same letter index on particular days (1, 7, 14, 21) do not differ significantly (P>0.05).
tial size are usually characterized by a faster growth rate than those that are initially larger (Kamler 1992; Wolnicki 2005).

Conclusions

The ability to rear larvae at high stocking densities could have a significant influence on production profitability (Kupren et al., 2008c; Turkowski et al., 2008b). This study is therefore valuable in demonstrating that initial rearing at higher stocking densities than previously reported can be successfully achieved (Wolnicki, 2005). A slight (or even absence) of differences in larvae growth rates after the first week (asp) or two initial weeks of rearing (ide, chub) indicates the possibility of applying densities reaching 400 individuals per 1 L during that period with a little risk of decreasing the growth rate. Although further rearing carried out at the highest densities involved a decrease in the growth rate, it would provide several times more fish for stocking from the same volume of water and at a uniform ontogenetic stage. Differences in the final fish size in various treatments could probably be reduced by a longer rearing time of fish at high densities, albeit at higher production costs.

References

Albrecht, M.L., Steffen, W., Schicknick, H., 1977. Versuche zur Aufzucht von Karpfenbrut Cyprinus carpio mit Trockenmischflutten. Z. Binnenfisch DDR 24:331-335.

Alvarez-Gonzalez, C., Ortiz-Galindo, J. L, Dumas, S., Martinez-Diaz, S., Hernandez-Ceballos, D.E., Grayeb-Del Alamo, T., Moreno-Legoretta, M., Pena-Martinez, R., Civera-Cerecedo, S., Martinez-Diaz, S., Hernandez-Ceballos, D., Mamcarz, A., 1998. Cryopreservation of asp, Aspius aspius (L.) sperm. Progr. Fish Cult. 60:146-148.

Baras, E., Kestemont, P., Melard, C., 2003. Effect of stocking density on the growth and survival spotted sand bass Paralabrax maculofasciatus larvae in a closed recirculating system. J. World Aquacult. Soc. 32:130-137.

Babiak, I., Glogowski, J., Kujawa, R., Kucharczyk, D., Mamcarz, A., 1998. Cryopreservation of asp, Aspius aspius (L.) spermi. Progr. Fish Cult. 60:146-148.

Baskerville-Bridges, B., Kling, L. J., 2000. Larval culture of Atlantic cod Gadus morhua at high stocking densities. Aquaculture 181:61-69.

Bolaisina, S., Tagawa, M., Yamashita, Y., Tanaka, T., 2006. Effect of stocking density on growth, digestive enzyme activity and cortisol level in larvae and juveniles of Japanese flounder, Paralichthys olivaceus. Aquaculture 259:432-443.

Cejko, B. I., Kowalski, R. K., Kucharczyk, D., Targórska, K., Krejzeff, S., Żarski, D., Glogowski, J., 2010. Influence of the length of time after hormonal stimulation on selected parameters of milt of ide Leuciscus idus L. Aquac. Res. 41:804-813.

Celada, J.D., Carral, J.M., Rodríguez, R., Saetz-Royuela, M., Agüílera, A., Melendre, P. M., Martín, J., 2007. Trench (Tinca tinca L.) larvae rearing under controlled conditions: density and basic supply of Artemia nauplii as the sole food. Aquacult. Int. 15:489-495.

Donabau, K., Schagerl, M., Dokulil, M. T., 1999. Integrated management to reduce macrophyte domination. Hydrobiologia 395/396:87-97.

Foss, A., Vollen, T., Oestad, V., 2003. Growth and oxygen consumption in normal and O2 supersaturated water, and interactive effects of O2 saturation and ammonia on growth in spotted wolffish (Anarhichas minor Olafsen). Aquaculture 224:105-116.

Gomulka, P., Zarski, D., Kucharczyk, D., Kupren, K., Krejzeff, S, Targórska, K., 2011. Acute ammonia toxicity during early ontogeny of chub, Leuciscus cephalus (Cyprinidae). Aquat. Living Resour. (In press).

Hamáčková, J., Prokeš, M., Kožák, P., Peřáč, M., Stanny, L. A., Polcar, T., Baruš, V., 2009. Growth and development of vimba bream (Vimba vimba) larvae in relation to feeding duration with live and/or dry starter feed. Aquaculture 287:158-162.

Hatziathanasiou, A., Paspatis, M., Houbart, M., Kestemont, P., Stefanakis, S., Kentouri, M., 2002. Survival, growth and feeding in early life stages of European sea bass (Dicentrarchus labrax) intensively cultured under different stocking densities. Aquaculture 205:89-102.

Imorou Toko, I., Flogbe, E. D., Kestemont, P., 2008. Development and growth of zebrafish larvae (Dicentrarchus labrax) under various stocking densities. Aquaculture 295:145-147.

Kamler, E., 1992. Early life history of fish: an energetics approach. Chapman & Hall Ed., London, UK.

Kamler, E., Keckeis, H., Bauer-Nemeschkal, E., 1998. Temperature-induced changes of survival, development and yolk partitioning in Chondrostoma nasus. J. Fish. Biol. 53:658-682.

Krejzeff, S., Kucharczyk, D., Kupren, K., Targórska, K., Mamcarz, A., Kujawa, R., Kaczkowski, Z., Ratajaki, S., 2008. Reproduction of chub, Leuciscus cephalus L., under controlled conditions. Aquac. Res. 39:907-912.

Krejzeff, S., Targórska, K., Żarski, D., Kucharczyk, D., 2009. Domestication affects spawning of the ide (Leuciscus idus) - preliminary study. Aquaculture 295:145-147.

Kucharczyk, D., Kujawa, R., Łuczynski, M., Glogowski, J., Babiak, I., Wyszmierska, E., 1997a. Induced spawning in bream, Abramis brama (L.), using carp and bream pituitary extract and hCG. Aquac. Res. 28:139-144.

Kucharczyk, D., Kujawa, R., Mamcarz, A., Targonska-Dietrich, K., Krejzeff, S., Wyszmierska, E., 2007. Artificial spawning of common tench (Tinca tinca L.) collected from wild populations. Pol. J. Nat. Sci. 22:37-45.

Kucharczyk, D., Kujawa, R., Mamcarz, A., Targonsa-Dietrich, K., Wyszmierska, E., Glogowski, J., Babiak, I., Szabo, T. 2005. Induced spawning in bream (Abramis brama L.) using pellets containing GnRH. Czech J. Anim. Sci. 50:93-95.

Kucharczyk, D., Kujawa, R., Mamcarz, A., Wyszmierska, E., 1997b. Artificial spawning in bream (Abramis brama L.) collected from wild populations. Pol. Arch. Hydrobiol. 44:203-207.

Kucharczyk, D., Łuczynski, M., Kujawa, R., Czerekies, P., 1997c. Temperature-induced changes of survival, development and yolk partitioning in embryonic and larval development of bream (Abramis brama L.). Aquatic Sci. 59:214-224.

Kucharczyk, D., Łuczynski, M., Kujawa, R., Kaminski, R., Ulkowski, D., Brzuzan, P., 1998. Influences of temperature and food on early development of bream (Abramis brama L.). Arch. Hydrobiol. 143:235-236.

Kucharczyk, D., Targórska, K., Łwiwa, P., Czejko, B.I., Glogowski, J., 2008. Comparing the effectiveness of Ovopel, Ovaprim and LH-RH analogue used in the controlled reproduction of ide, Leuciscus idus (L.). Arch. Pol. Fish. 16:363-370.

Wyszomirska, E., 1997b. Artificial spawning in bream (Abramis brama L.) collected from wild populations. Pol. J. Nat. Sci. 22:37-45.
Kucharczyk, D., Targońska, K., Żarski, D., 2004. A review of the reproduction biotechnology for fish from the genus Leuciscus. Arch. Pol. Fish. 16:319-340.

Kujawa, R., 2004. Biologiczne podstawy podchowa larw reofilnych ryb karpiowatych w warunkach kontrolowanych. Rozprawy i monografie, Wyd. UWM Publ., Olsztyn, Poland.

Kujawa, R., Kucharzcyk, D., Mamcarz, A., 1999. A model system for keeping spawners of wild and domestic fish before artificial spawning. Aquat. Eng. 20:85-89.

Kujawa, R., Kucharzcyk, D., Mamcarz, A., Skrzypczak, A., 1998. The rearing methods of ide (Leuciscus idus L.) and dace (Leuciscus leuciscus L.) on artificial diets. Eur. Aquacult. Soc. Spec. Publ. 26:153-154.

Kujawa, R., Mamcarz, A., Kucharzcyk, D., 1997. Effect of temperature on embryonic development of asp (Aspius aspius L.). Pol. Arch. Hydrobiol. 44:139-143.

Kupren, K., Kucharzcyk, D., Prusiszka, M., Krejszef, S., Targońska, K., Mamcarz, A., 2008a. The influence of stocking density on survival and growth of Buenos Aires Tetra (Hemigrammus caudovittatus) larvae reared under controlled conditions. Pol. J. Nat. Sci. 23:881-887.

Kupren, K., Mamcarz, A., Kucharzcyk, D., 2010. Effects of temperature on survival, deformations rate and selected parameters of newly hatched larvae of three rheophilic cyprinids (genus Leuciscus). Pol. J. Nat. Sci. 25:299-312.

Kupren, K., Mamcarz, A., Kucharzcyk, D., 2011. Effect of variable and constant thermal conditions on embryonic and early larval development of fish from the genus Leuciscus (Cyprinidae, Teleostei). Czech J. Anim. Sci. 56:70-80.

Kupren, K., Mamcarz, A., Kucharzcyk, D., Prusiszka, M., Krejszef, S., 2008b. Influence of water temperature on eggs incubation time and embryonic development of fish from genus Leuciscus. Pol. J. Nat. Sci. 23:461-481.

Kupren, K., Turkowski, K., Kucharzcyk, D., Krejszef, S., Żarski, D., Hakuć-Blążowska, A., Targońska, K., Kwiatkowski, M., Jamróz, M., Czarkowski, T., 2008b. Economic aspects of rearing larval asp Aspius aspius (L) and ide Leuciscus idus (L) in closed recirculating system. Arch. Pol. Fish. 16:423-430.

Kwiatkowski, M., Żarski, D., Kucharzcyk, D., Kupren, K., Jamróz, M., Targońska, K., Krejszef, S., Hakuć-Blążowska, A., Kujawa, R., Mamcarz, A., 2008. Influence of feeding natural and formulated diets on chosen rheophilic cyprinid larvae. Arch. Pol. Fish. 16:383-396.

Lahnsteiner, F., Berger, B., Horvath, A., Weismann, T., 2003. Cryopreservation of spermatozoa in cyprinid fishes. Theriogenology 54:1477-1498.

Lahnsteiner, F., Berger, B., Weismann, T., 2003. Effect of media, fertilization technique, extender, straw volume and sperm to egg ratio on hatchability of cyprinid embryos. Raising cryopreserved semen. Theriogenology 60:829-841.

Mamcarz, A., 2008. Boleń, Aspius aspius, Linnaeus 1758. pp 130-177 in: Larwikultura reofilnych ryb karpiowatych. Mercurius Kaczmarek Andrzej Publ., Olsztyn, Poland.

Mamcarz, A., Targońska, K., Kucharzcyk, D., Kujawa, R., Żarski, D., 2011. Effect of live and dry food on rearing of tench (Tinca tinca L.) larvae under controlled conditions. Ital. J. Anim. Sci. 10:e9.

Papoutsoglou, S. E., Tziga, G., Vrettos, X., Athanasio, A., 1998. Effects of stocking density on behavior and growth rate of European sea bass (Dicentrarchus labrax) juveniles reared in a closed circulated system. Aquacul. Eng. 18:135-144.

Peñaz, M., Prokeš, M., Kouril, J., Hamackova, J., 1983. Early development of the carp, Cyprinus carpio. Acta. Sc. Nat. Brno. 17(2):1-39.

Polář, T., Kožák, P., Hamáčková, 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. Living Resour. 20:175-183.

Rafatnezhad, S., Falahatkar, B., Tolouei Gilani, M. H., 2008b. Prawne i ekonomiczne podstawy gospodarowania karpiowatymi rybami reofilnymi. Wyd. Mercurius Kaczmarek A. Ed., Olsztyn, Poland.

Rafatnezhad, S., Falahatkar, B., Tolouei Gilani, M. H., 2008. Effects of stocking density on haematological parameters, growth and fin erosion of great sturgeon (Huso huso) juveniles. Aquac. Res. 39:1506-1513.

Saunders, D. L., Meeuwig, J. J., Vincent, A. C., 2002. Freshwater protected areas: strategies for conservation. Conserv. Biol. 16:30-41.

Shiri Harzevili, A., De Charleroy, D., Auwerx, J., Vught, I., Van Slycken, J., 2003. Larval rearing of chub, Leuciscus cephalus (L.), using decapsulated Artemia as direct food. J. Appl. Ichthyol. 19:123-125.