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RESEARCH ARTICLE

# Impact of feed ration on the growth and body weight variation in pikeperch (*Sander lucioperca* L.) at different life stages in a recirculating aquaculture system

**Michał Kozłowski, Mirosław Szczepkowski, Iwona Piotrowska, Bożena Szczepkowska**

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**Abstract.** The aim of the study was to determine the impact of different feed rations (0.5, 0.8, 1.1% fish biomass) on the rearing parameters of pikeperch, *Sander lucioperca* (L.), reared in a recirculating aquaculture system. The study comprised two experiments. In the first, the material used had been sorted by a mean body weight of 35.5 g, while in the second the pikeperch were divided into three size classes: smallest individuals (class S) with a mean body weight of 59.5 g, medium-sized individuals (class M) with a mean weight of 69.3 g, and largest individuals (class L) with a mean body weight of 84.8 g. The experiments ran for 42 days. At the conclusion of the experiments, the highest body weight and length, daily growth rate, and specific growth rate were attained by the group of fish fed the ration of 1.1% of the fish biomass in both experiments I and II. The feed conversion ratio was also the lowest in this feed ration group, and it differed significantly statistically among the experimental groups ($P < 0.05$). The feed ration of 0.5% of the fish biomass was only sufficient to maintain vital functions, but it contributed only slightly to growth. The different feed rations did not have a significant impact on the final value of the body weight coefficient of variation of the pikeperch reared in the two experiments. The results of the experiment also indicated that pikeperch is a species with weak stock hierarchy and domination structure.

M. Kozłowski[✉], M. Szczepkowski, I. Piotrowska, B. Szczepkowska
Department of Sturgeon Fish Breeding in Pieczarki,
Inland Fisheries Institute in Olsztyn, Poland
e-mail: m.kozlowski@infish.com.pl

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## Introduction

Interest has been growing in the production of Percidae fishes, and especially of pikeperch, *Sander lucioperca* (L.), in recent years in Central and Eastern Europe. Since this species holds great promise for European aquaculture (Zakęś 2009), many research projects are being conducted with the aim of improving pikeperch rearing methods in recirculating aquaculture systems (RAS) (Ljubobratović et al. 2016, Mattila and Koskela 2018, Molnár et al. 2018, Policar et al. 2013, 2016, Steenfeldt 2015).

Most fish species reared in aquaculture exhibit substantial fluctuation in body size. Knowledge on managing individual body weight fluctuations and feed ingestion leads to maximizing production efficiency by reducing feed waste and improving water quality (McCarthy et al. 1992, Jobling and Baardvik 1994). This is particularly important in the production of Percidae fishes since they are highly sensitive to water physico-chemical changes, and even low concentrations of nitrites and ammonia can be harmful to them (Fontaine et al. 1997, Zakęś 1999, Stejskal et al. 2009).

In some fish species cannibalism, or mortality, is attributed to increased variation in body size (Baras and Jobling 2002). The establishment of a social hierarchy was recognized as the most important factor determining increased variation in body weight that is observed in fish (Metcalfe 1986, Johnsson 1997). Dominant fish are usually considered to be the larger individuals that have an inhibitory effect on the growth and feed consumption of smaller, subordinate fish (Cutts et al. 1998). Sorting is the only procedure that is conducted routinely that minimizes body size variation. This procedure changes the composition from heterogeneous groups to those that are homogeneous and of various sizes. Thus, it is assumed that the social hierarchy is disturbed and small fish have the opportunity to compensate their growth in the absence of larger fish (Jobling 1982, 1995). Several studies tested this assumption, and the results were contradictory. For some species it was demonstrated that small fish equalized their growth leading to increased biomass (Brzeski and Doyle 1995, Seppä et al. 1999). However, for many other fish species sorting did not have an advantageous impact on the growth of small fish (Jobling and Reinsnes 1987, Baardvik and Jobling 1990, Kamstra 1993, Sunde et al. 1998).

Some studies on pikeperch sorting also indicated that this procedure did not improve yield in the production of pikeperch (Zakęś et al. 2004, Szczepkowski et al. 2011). Additionally, the procedure can be stressful to the fish, which is manifested in their not feeding for a few days, which results in the lowered effectiveness of production (Kozłowski et al. 2009). This is why we conducted the experiments in which we tested the impact of feed rations on different pikeperch life stages in RAS. In the first experiment the reared pikeperch were of similar body weights, while in the second experiment was comprised of three different pikeperch size classes. The aim of the study was to determine the impact of different feed rations on growth and body weight variations in pikeperch.

## Materials and methods

### Material, origin, and initial rearing conditions

The experimental material was juvenile pikeperch obtained from artificial spawning that was reared at the Department of Sturgeon Fish Breeding in Pieczarki, Inland Fisheries Institute in Olsztyn (Zakęś and Szczepkowski 2004, Zakęś 2009). The experiments were conducted in a RAS fitted with an SDK CN 3.2 biofilter with a volume of 3.2 $m^3$ (SDK Poland), which was filled with synthetic Light Bioelementer with a combined volume of 1.5 $m^3$ (RK Plast A/S, Dania). The filter thickness was 0.93 g $cm^{-3}$, and its surface area proper was 750 $m^2$ $m^{-3}$. The fish were reared in square tanks with a volume of 1 $m^3$. The fish were trained to take commercial feed according to established procedures (Kestemont et al. 2007, Zakęś 2009). After the 14-day acclimatization period, during which the fish were trained to take commercial feed, the material was reared for a further four months. Next, some of the fish were moved to a different RAS fitted with the same set of tanks where the experiment proper was conducted.

### Experiment design

Water flow in the tanks was maintained at a constant rate of 12 l $min^{-1}$. Water temperature was maintained at 20.0°C. Oxygen concentration at the tank outflows was not less than 5.3 mg $O_2$ $l^{-1}$, and the water pH range was 7.6-7.7. Measurements of these parameters were taken with a Cyber Scan 5500 meter (Eutech Instruments, USA). Ammonia nitrogen (CAA = $NH_4^+$-N + $NH_3$-N) at the tank outflows did not exceed 0.12 mg CAA $l^{-1}$, while nitrites did not exceed 0.02 mg $NO_2$- $l^{-1}$. These parameters were measured with a spectrometer system (Carl Zeiss 11, Germany) (Hermanowicz et al. 1999). All of these physico-chemical parameters were measured at least once weekly.

During the experiment, the fish were fed E-1P Stella by Nutreco (France) with a granulation of 2.5 mm comprising 47% protein, 14% lipid, and 21% carbohydrates. The digestible energy of the feed was 18.5 MJ $kg^{-1}$. The feed was delivered using an automatic band feeder for 18 h $d^{-1}$.

Two experiments were conducted in which three feed rations were tested: 0.5% (group F 0.5), 0.8% (group F 0.8), and 1.1% (group F 1.1) of the fish biomass in the tanks. The stock of each tanks was 30 fish and each of the experimental variants were conducted in three replicates. Each experiment was run for 42 d. In experiment I each tank was stocked with pikeperch with a mean body weight of 35.5 ± 0.5 g and a body length of 14.5 ± 0.1 cm. In experiment II, the pikeperch had a mean body weight of 71.2 ± 0.3 g and a body length of 18.3 ± 0.1 cm. All fish were tagged individually with Carlin tags attached near the dorsal fin. The pikeperch in experiment II were divided into three size classes: the smallest individuals (class S) with a mean body weight of 59.5 g and a range of 50-65 g; medium-sized individuals (class M) with a mean body weight of 69.3 g and a range of 66-74 g; and the largest individuals (class L) with a mean body weight of 84.8 g and a range of 75-100 g. The stock in each tank comprised 10 individuals of each size class for a total of 30 individuals.

## Experimental procedure and statistical analysis

The tanks were cleaned daily of excrement and unconsumed feed, and the condition and mortality of the fish were observed. To determine the rearing parameters, every 7 d individual measurements of fish body length (± 1 mm) and weight (± 0.1 g) were taken. The number of individuals with bite marks was also noted. Experimental manipulations and tagging were performed with the anesthetic Propiscin (Kazuń and Siwicki 2001) at a concentration of 1 ml $l^{-1}$ water.

The data collected was used to calculate the following parameters: daily growth rate DGR (g $d^{-1}$) = $(BW_2 - BW_1) \times t^{-1}$; specific growth rate SGR (% $d^{-1}$) = $100 \times (\ln BW_2 - \ln BW_1) \times t^{-1}$; Fulton's condition coefficient $K = 100 \times BW_m \times Lt^{-3}$; feed conversion ratio $FCR = TFC \times (FB - IB)^{-1}$; body weight coefficient of variation CV (%) = $100 \times SD \times BW^{-1}$; stock survival P (%) $=100 \times (FN \times IN^{-1})$; where: $BW_1$ – initial body weight (g), $BW_2$ – final body weight (g), BW – body weight (g), $BW_m$ – mean body weight (g), t – rearing time (d), Lt – total length (cm), SD – body weight standard deviation, IB – initial fish biomass (g), FB – final fish biomass (g), IN – initial number of fish (ind.), FN – final number of fish (ind.), TFC – total feed consumption (g).

In experiment II, the stability of stock hierarchy was calculated as the percentage of individuals that remained in the same size class from the initial to the concluding days of the experiment (Zakęś et al. 2001). The higher the stock hierarchy percentage obtained, the more stable the stock was.

The results are presented as means ± standard deviation (SD). Statistical differences in experiments I and II were analyzed with one-way analysis of variance (ANOVA). Levene's test was used to check homogeneity of variance. Tukey's post-hoc test was used to determine statistically significant differences among groups ($P < 0.05$). Values expressed in percentages were arcsine transformed before statistical analyses. Statistical calculations were performed with STATISTICA 12 PL (StatSoft Poland).

# Results

## Experiment I

In this experiment the greatest body weight growth was noted in group F 1.1, and it was 13.6 % higher than that of group F 0.8 and 26.5% than that of group F 0.5 ($P < 0.05$, Table 1). Pikeperch body length also differed significantly statistically among all the groups. DGR was highest in group F 1.1 at 0.49 g $d^{-1}$, which differed statistically from all the other groups. SGR differed significantly statistically among the groups. The lowest value for the feed conversion ratio (1.00) was noted in group F 1.1, and it differed significantly statistically from that of group F 0.5. The remaining parameters did not differ significantly statistically among the groups tested ($P > 0.05$).

## Experiment II

After six weeks of rearing, the highest mean body weight was attained in group F 1.1 and was 107.8 g. The final body weight in this group was 12.7% higher than in group F 0.8 and 24.9% higher than in group F 0.5 ($P < 0.05$, Table 1). The final body lengths among the tested groups differed significantly statistically. DGR of the fish fed the largest daily feed ration was 3.8 times higher than in the group that was fed the lowest feed ration (Table 2). SGR values ranged from 0.30 % $d^{-1}$ (group F 0.5) to 0.99% in group F 1.1, and the differences among groups were statistically significant. The FCR in group F 1.1 was 1.07, which differed significantly statistically from group F 0.5 (Table 2). The final body weight coefficient of variation values in all groups ranged from 26.0 to 28.5% and did not differ significantly statistically. Fish survival in the experiment was 100%. The different feed rations applied did not have a statistically significant impact on the stock hierarchy stability. Individuals with distinct bite marks from other fish were observed during rearing, and on the final day of the experiment, the number of these fish was 2.2% of all fish in groups F 0.5 and F 1.1. Only in group F 0.8 were no bitten individuals confirmed.

## The impact of feed rations on rearing results depending on initial fish size

### Class S – smallest individuals

Increased feed rations had a statistically significant impact on the final body weight of the smallest pikeperch. The highest body weight was noted in the fish from group F 1.1 and was higher by 13% from that of group F 0.8 and by 24% from that of group F 0.5 ($P < 0.05$, Table 2). The pikeperch from group F 1.1 attained the greatest body length, which differed significantly statistically from the other groups tested. The highest values of SGR were recorded in group F 1.1 at a value of 0.97% $d^{-1}$, and this differed statistically from the other groups tested. The highest condition coefficient was recorded for the pikeperch from group F 1.1, and it differed statistically from that of the fish from group F 0.5. No statistically significant differences in stock hierarchy stability were noted, while the highest value was recorded in group F 1.1 at 56.7%. At the end of the experiment individuals with bite marks were observed only in group F 0.5 at a share of 3.3%.

**Table 1**

Final results of rearing pikeperch fed different feed rations in experiment I (0.5% fish biomass (group F 0.5), 0.8% (group F 0.8), 1.1% (group F 1.1), mean values ± SD, n = 3)

| Parameter | Group F 0.5 | Group F 0.8 | Group F 1.1 |
|---|---|---|---|
| Body weight (BW, g) | $40.5 \pm 0.5^a$ | $47.6 \pm 0.8^b$ | $55.1 \pm 0.3^c$ |
| Body length (SL, cm) | $15.7 \pm 0.1^a$ | $16.3 \pm 0.1^b$ | $16.9 \pm 0.1^c$ |
| Daily growth rate (DGR, g $d^{-1}$) | $0.12 \pm 0.01^a$ | $0.29 \pm 0.01^b$ | $0.47 \pm 0.00^c$ |
| Specific growth rate (SGR, % $d^{-1}$) | $0.30 \pm 0.02^a$ | $0.70 \pm 0.03^b$ | $1.06 \pm 0.01^c$ |
| Condition factor (CF) | $1.0 \pm 0.1^a$ | $1.1 \pm 0.1^a$ | $1.1 \pm 0.1^a$ |
| Feed conversion ratio (FCR) | $1.63 \pm 0.12^a$ | $1.10 \pm 0.04^b$ | $1.00 \pm 0.01^b$ |
| Body weight coefficient of variation (CV, %) | $19.1 \pm 4.5^a$ | $18.6 \pm 3.0^a$ | $17.1 \pm 0.8^a$ |
| Survival (%) | $100.0 \pm 0.0^a$ | $100.0 \pm 0.0^a$ | $100.0 \pm 0.0^a$ |
| Bitten fish (%) | $1.1 \pm 1.9^a$ | $0.0 \pm 0.0^a$ | $3.3 \pm 3.3^a$ |

* values in the same rows with the same letter indexes do not differ significantly statistically ($P > 0.05$)

**Table 2**
Final results of rearing pikeperch fed different feed rations in experiment II (0.5% fish biomass (group F 0.5), 0.8% (group F 0.8), 1.1% (group F 1.1), mean values ± SD, n = 3)

| Parameter | Group F 0.5 | Group F 0.8 | Group F 1.1 |
|---|---|---|---|
| Body weight (BW, g) | 81.0 ± 0.8[a] | 94.1 ± 0.8[b] | 107.8 ± 1.7[c] |
| Body length (SL, cm) | 19.5 ± 0.2[a] | 20.1 ± 0.1[b] | 20.6 ± 0.1[c] |
| Daily growth rate (DGR, g $d^{-1}$) | 0.23 ± 0.02[a] | 0.53 ± 0.02[b] | 0.87 ± 0.04[c] |
| Specific growth rate (SGR, % $d^{-1}$) | 0.30 ± 0.02[a] | 0.67 ± 0.02[b] | 0.99 ± 0.04[c] |
| Condition factor (CF) | 1.1 ± 0.1[a] | 1.1 ± 0.1[a] | 1.2 ± 0.1[a] |
| Feed conversion ratio (FCR) | 1.60 ± 0.09[a] | 1.17 ± 0.03[b] | 1.07 ± 0.05[b] |
| Body weight coefficient of variation (CV, %) | 26.0 ± 3.9[a] | 28.5 ± 7.4[a] | 26.2 ± 2.6[a] |
| Survival (%) | 100.0 ± 0.0[a] | 100.0 ± 0.0[a] | 100.0 ± 0.0[a] |
| Stable dominance hierarchy (%) | 42.2 ± 3.8[a] | 51.1 ± 15.0[a] | 52.2 ± 8.4[a] |
| Bitten fish (%) | 2.2 ± 3.8[a] | 0.0 ± 0.0[a] | 2.2 ± 3.8[a] |

* values in the same rows with the same letter indexes do not differ significantly statistically (P > 0.05)

### Class M – medium-sized individuals

The pikeperch from group F 1.1 attained the highest body weight by the end of the experiment. They gained 114.6 g and differed statistically from the fish from group F 0.5. The longest body length was noted in group F 1.1, and it also differed statistically from that of group F 0.5. The highest SGR value of 1.17% $d^{-1}$ was noted in group F 1.1, and it was in excess of three-fold higher that of group F 0.5 (P < 0.05). The condition coefficient of the pikeperch from group F 1.1 was 1.24 and differed statistically from that of group F 0.5. The remaining parameters of rearing pikeperch did not differ statistically (Table 3).

### Class L – largest individuals

Among class L fish the highest body weight gain was also recorded in group F 1.1 in which the final mean body weight was 118.6 g. This was statistically significant in comparison to group F 0.5. The pikeperch from group F 1.1 attained the longest body length, which differed statistically from group F 0.5. SGR was the lowest in group F 0.5, and this value was two-fold lower than that in group F 0.8 and three-fold lower than in group F 1.1.

## Discussion

The feed rations applied in the experiment had significant effects on some of the pikeperch rearing parameters. DGR values increased when the feed ration was increased from 0.5 to 1.1 % of the fish biomass. The highest gains were noted in the fish fed the ration of 1.1 % of fish biomass in both experiments I and II. The SGR values obtained at the initial pikeperch size (range 35-100 g) were similar to those reported by other authors in papers on pikeperch rearing (Nina-Wamwiza et al. 2005, Kozłowski et al. 2008, Rónyai and Csengeri 2008, Zakęś 2009). However, comparing growth rates and feed use efficiency values with those of other studies may be difficult considering that fish DGR and FCR values decrease as body weight increases (Brett and Groves 1979, Fiogbe and Kestemont 2003).

Growth rate and feed ration size affect the feed conversion ratio and are used to estimate the requirements of given stocks of fish. The modest growth and high feed conversion ratio in the pikeperch fed the ration of 0.5% in the experiment suggests that this ration size was mostly used to maintain vital function and less so for growth. The same results were obtained when rearing pike, *Esox lucius* L., and perch, *Perca fluviatilis* L. (Kozłowski et al. 2012, 2013). The

**Table 3**

Final results of rearing pikeperch from three size classes (class S – smallest individuals, class M – medium-sized individuals, class L – largest individuals) fed different feed rations in experiment II (0.5% fish biomass (group F 0.5), 0.8% (group F 0.8), 1.1% (group F 1.1), mean values ± SD, n = 3)

| | Class S | | | Class M | | | Class L | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | Group F 0.5 | Group F 0.8 | Group F 1.1 | Group F 0.5 | Group F 0.8 | Group F 1.1 | Group F 0.5 | Group F 0.8 | Group F 1.1 |
| Body weight (BW, g) | 68.5 ± 3.6$^{a}$ | 78.4 ± 2.7$^{b}$ | 90.1 ± 3.7$^{c}$ | 79.3 ± 5.9$^{a}$ | 94.3 ± 12.7$^{ab}$ | 114.6 ± 2.7$^{b}$ | 95.1 ± 2.7$^{a}$ | 109.5 ± 8.6$^{ab}$ | 118.6 ± 4.2$^{b}$ |
| Body length (SL, cm) | 18.4 ± 0.2$^{a}$ | 19.0 ± 0.2$^{b}$ | 19.5 ± 0.1$^{c}$ | 19.5 ± 0.4$^{a}$ | 20.1 ± 0.6$^{ab}$ | 20.8 ± 0.1$^{b}$ | 20.7 ± 0.2$^{a}$ | 21.2 ± 0.5$^{a}$ | 21.4 ± 0.2$^{a}$ |
| Specific growth rate (SGR, % $d^{-1}$) | 0.34 ± 0.08$^{a}$ | 0.67 ± 0.06$^{b}$ | 0.97 ± 0.09$^{c}$ | 0.34 ± 0.16$^{a}$ | 0.72 ± 0.32$^{ab}$ | 1.17 ± 0.05$^{b}$ | 0.25 ± 0.05$^{a}$ | 0.58 ± 0.21$^{b}$ | 0.84 ± 0.08$^{b}$ |
| Condition factor (CF) | 1.07 ± 0.03$^{a}$ | 1.11 ± 0.01$^{ab}$ | 1.18 ± 0.05$^{b}$ | 1.06 ± 0.03$^{a}$ | 1.14 ± 0.07$^{ab}$ | 1.24 ± 0.03$^{b}$ | 1.05 ± 0.05$^{a}$ | 1.12 ± 0.03$^{ab}$ | 1.18 ± 0.05$^{b}$ |
| Body weight coefficient of variation (CV, %) | 22.3 ± 2.9$^{a}$ | 20.7 ± 14.7$^{a}$ | 15.3 ± 10.9$^{a}$ | 22.4± 3.4$^{a}$ | 19.8 ± 13.9$^{a}$ | 18.1 ± 11.4$^{a}$ | 21.4 ± 3.9$^{a}$ | 26.1 ± 5.7$^{a}$ | 26.2 ± 4.9$^{a}$ |
| Survival (%) | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ | 100.0 ± 0.0$^{a}$ |
| Stable dominance hierarchy (%) | 50.0 ± 10.0$^{a}$ | 50.0 ± 20.0$^{a}$ | 56.7 ± 15.3$^{a}$ | 23.3 ± 5.8$^{a}$ | 40.0 ± 26.5$^{a}$ | 36.7 ± 11.6$^{a}$ | 53.3 ± 11.6$^{a}$ | 63.3 ± 11.6$^{a}$ | 63.3 ± 5.8$^{a}$ |
| Bitten fish (%) | 3.3 ± 5.8$^{a}$ | 0.0 ± 0.0$^{a}$ | 0.0 ± 0.0$^{a}$ | 3.3 ± 5.8$^{a}$ | 0.0 ± 0.0$^{a}$ | 0.0 ± 0.0$^{a}$ | 3.3 ± 5.8$^{a}$ | 0.0 ± 0.0$^{a}$ | 3.3 ± 5.8$^{a}$ |

* Groups marked with different letter indexes (with a given fish size class) differ significantly statistically ($P < 0.05$)

results of the present study largely concur with the observations made by Khan et al. (2004) during the rearing of *Cirrhinus mrigala* (Hamilton).

In the present study, the different feed rations were not noted to have had a significant impact on the final values of the body weight coefficient of variation (CV) in the pikeperch reared in the two experiments. This coefficient increased during rearing in all of the groups tested. The same results were obtained by Rónyai and Csengeri (2008) while rearing pikeperch at different water temperatures. According to the authors, neither feed rations nor water temperatures impacted differences in body weight. These observations do not concur with the results of Zakęś et al. (2003) that confirm a substantial decrease in pikeperch body weight variation in groups of fish fed the largest rations.

These contradictory results indicate that other factors such as initial fish size, rearing system, stocking density, and feed quality can impact the size distribution of Percidae fishes (Kestemont et al. 2003). According to Molnár et al. (2004), fish stocks, within certain limits, do not impact increases of body weight, the feed conversion ratio or cannibalism in juvenile pikeperch. Only natural mortality decreases as stocking density increases. At a stocking density of 50-60 fish $m^{-3}$, Fontaine et al. (1995) observed increased CV in European perch in floating cages, while this parameter remained stable when this species was reared in RAS. However, when stocking density exceeded 20 kg $m^{-3}$, Arctic charr, *Salvelinus alpinus* (L.), social interactions were partially inhibited, which, consequently, reduced variations in fish sizes (Jobling et al. 1993). According to Kadri et al. (1996), how feed is delivered is also an important factor that impacts variations in fish body weight, and these authors suggest that feed should be delivered in a manner that is unpredictable both spatially and temporally to avoid feed being monopolized by dominant individuals.

Small feed rations can cause rapid increases in activity in some fish species during feeding. This is a significant stress factor that contributes to mutual aggression, and this phenomenon is often observed in controlled fish culture (Baras et al. 2000). Commonly it occurs in fish that exhibit aggressive behavior during periods of limited or low access to feed and at high stocking densities (Koebele 1985, Sloman and Armstrong 2002). In the present study, pikeperch that had been bitten were only observed in small numbers in the groups with the lowest and the highest feed rations (2 fish for the group; 2.2%) in both experiments. These results indicate that this species behaves calmly when fed under controlled conditions. The feed rations applied in the current study did not result in increased aggression. These results are contradictory to those of rearing perch in the same manner, when the number of bitten fish ranged from 28.6 to 46.0% depending on the feed ration, which is evidence that the mutual aggression perch exhibited during feeding depended on the size of the feed ration delivered to them. Aggression among perch decreased with increased feed rations (Kozłowski et al. 2013). Even though pikeperch and perch belong to the family Percidae, their behavior during feeding in RAS differs.

Culturing different fish size classes in a stock does not always lead to initiating strong interactions among individuals of different sizes, and, consequently, to the establishment of domination and hierarchization (Baardvik and Joblinga 1990, Sunde et al. 1998, Stefánsson et al. 2000). In some fish species it is persistence (e.g., endurance and agility) rather than dominance that determines feeding behavior. The larger size of dominant fish is likely the consequence and not the cause of social domination (Baardvik and Jobling 1990, Huntingford et al. 1990, Stefánsson et al. 2000, Sloman and Armstrong 2002). Additionally, the effect of size on social dominance can shift in subsequent fish life stages and from environmental conditions.

The results of experiment II showed that pikeperch is a species that exhibits weak stock hierarchy. This was maintained to the greatest degree in group F 1.1, in which 52.2 % of the fish remained in the same size class at the conclusion of the experiment. The results obtained differ from those for perch since the stock hierarchy remained stable. This was maintained to the greatest degree in the group of fish fed the smallest feed ration (0.5%), and in which 81% of the fish remained in the same size class at the conclusion of the experiment (Kozłowski et al. 2013). Differences were also apparent when comparing the results of pikeperch to those of pike, another predatory fish. Just like perch, pike was a very stable fish in terms of stock hierarchy. Stock stability was maintained in the group of fish fed the smallest feed ration with 91.1% of the fish remaining in the same size class at the conclusion of the experiment (Kozłowski et al. 2012).

Taking into consideration the different size classes, the group of the largest individuals (class L) remained the most stable group. The greatest changes expressed by stock hierarchy stability were noted in class M. The intermediate size of the pikeperch most likely impacted its behavior. A large portion of individuals from this size class shifted status to higher (L) or lower (S) size classes. Individuals in this size class were characterized by great flexibility in body weight changes. This observation concurs with previous studies on pike and perch in which fish of this size class shifted their size class status (Kozłowski et al. 2012, 2013).

The feed rations applied in the current study could have led to increased feed competition (Davis and Olla 1987, Grant 1993, Jobling 1995). They did not, however, increase the phenomenon of domination and hierarchization in fish stocks or variations in pikeperch body weight in either homogeneous or heterogeneous groups of fish. The SGR of the fish reared in the two experiments did not differ significantly; this suggests that in experiment II the presence of large fish did not impact the activity of small fish since social hierarchy did not play an important role in explaining the phenomenon of body weight variation in pikeperch. These conclusions confirm the opinions of Doyle and Talbot (1986) and Martins et al. (2005) who report that increasing body weight variations over time are not caused by social interactions in which larger, dominant, fish suppress the growth of smaller, subordinate, fish. Consequently, this suggests that increases in body weight variations are not necessarily linked with the creation of social hierarchies. Other factors such as differences in physiological reactions can be responsible for increased body weight variations (Jobling and Reinsnes 1986, Wickins 1987, Sunde et al. 1998). The results of the study also indicated that the feed rations of 0.8 and 1.1% of the fish biomass were sufficient to meet the demands of pikeperch reared under controlled conditions. This fact also confirms that opinion that pikeperch is a species with a weak stock hierarchy and domination structure. Zakęś et al. (2003) also came to the same conclusions when testing the impact of the size of daily feed rations on rearing pikeperch.

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**Author contributions.**M.K. designed the research; M.K., M.S., I.P., B.S. performed the research; M.K., M.S. analyzed the data; M.K, M.S. wrote the paper.

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