Effect of feeding frequency on growth and size variation in juvenile pikeperch, *Sander lucioperca* (L.)

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ABSTRACT: The aim of the investigation was to determine the effect of feeding frequency (one or three rations or continuous feeding with artificial feed) on the juvenile pikeperch (*Sander lucioperca*) growth rate, intra-group body weight variability and feed utilization. Two experiments were conducted. In the first experiment, the fish (approximate initial body weight 5 g) were fed in excess (5.0–3.5% of stock biomass) while in the second (approximate initial body weight 21 g) a restricted feed ration (1.0–0.8% of stock biomass) was applied. The fish were reared in cylindrical tanks that were a part of the recirculating system. The applied feeding frequencies did not have a significant effect on the analyzed zootechnical parameters (body weight, condition factor, intra-group body weight variability, feed conversion ratio). This pertained to both the fish fed in excess and the restricted regime.

Keywords: *Sander lucioperca*; feeding schedule; feed ration; growth; size dispersion

Developing intensive production methods for a given species requires to determine environmental preferences, including those pertaining to feeding. The analysis of feed requirements should include the daily feed ration as well as the chemical composition of feed (primarily protein and fat content), caloric content, size of pellets as well as their shape, colour and texture (Higuera, 2001). The effects of rearing fish under intensive conditions are determined not only by the quantity and quality of feed but also by the method employed to deliver it (manual or automated feeding) and by the feeding frequency (Alanärä et al., 2001). Feeding frequency may have an effect on fish growth rate, feed utilization efficiency, and intra-group size variation of fish (phenomena of domination and hierarchy in stocks). This factor was analyzed in numerous scientific investigations (e.g. Jobling, 1983a,b; Alanärä, 1992; Johansen and Jobling, 1998; Brännäs and Linnér, 2000; Lambert and Dutil, 2001; Petursdottir, 2002). The results of investigations conducted on various fish species are not unequivocal. The effect of feeding frequency is not only species specific; it also depends on the given developmental stage (size) of the fish (Folkvord and Otterå, 1993; Linnér and Brännäs, 2001; Giberson and Litvak, 2003). In intensive rearing, particularly in recirculating systems, feeding frequency may influence fish growth both directly and indirectly as it can affect water quality and oxygen and ammonia concentrations (Phillips et al., 1998).

Competition for food increases when it is limited or when restricted feeding is applied (McCarthy et al., 1992; Jobling, 1995). Under such conditions fish growth is often reduced and the importance of the phenomena of domination and hierarchy increases within the stock (Jobling, 1983a). It appears that the effects of feeding frequency on growth and intra-group size variability might be more apparent when restricted feeding is applied.

In practice, when fish are fed frequently with automated feeders, it is difficult to ensure that the conditions will allow for each individual to feed to satiation during each feeding. During low frequency feeding a portion of the feed is not consumed by the fish and falls to the bottom (this occurs with

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fish that feed from the water column exclusively). In this case, feeding frequency is increased and the feed is delivered in a greater number of rations throughout the daily cycle. Johansen and Jobling (1998) observed that the Atlantic salmon, *Salmo salar*, fed at a lower frequency were less active. They also determined that there were greater size variations among fish fed more frequently with an automatic feeder. These authors did not note that feeding frequency had an effect on the average growth rate of fish.

The aim of the present experiment was to determine the effect of feeding frequency (artificial feed delivered by an automatic feeder) on growth, intra-group variability, and feed conversion ratio in the juvenile pikeperch, *Sander lucioperca* (L.), reared in a recirculating system. Two experiments were conducted: in the first experiment the fish were fed in excess while in the second a restricted feeding regime was applied.

MATERIAL AND METHODS

Material and technical conditions. The material was obtained from out-of-season pikeperch spawning (Zakęś and Szczepkowski, 2004). The spawning and initial rearing of larval and juvenile stages were conducted at the Dgał Experimental Hatchery, Inland Fisheries Institute in Olsztyn (IFI). After having attained an average body weight of approximately 4.5 g, about 1 000 individuals were transported to the Aquaculture Department at the IFI.

Two experiments were conducted:

Experiment I – the experimental material comprised the juvenile pikeperch of average initial body weight (BW) of 4.8 g and total length (TL) of 8.3 cm (Table 1). The fish were fed in excess for a rearing period of six weeks.

Experiment II – the material obtained from experiment I (BW 21.0 g, TL 13.0 cm; Table 2) was collected into one tank and then randomly divided and placed into the tanks used in experiment I. The fish were reared for the next eight weeks on restricted feeding rations that were calculated on the basis of previous research (Zakęś et al., 2003).

The fish were reared in cylindrical tanks with a volume of 0.2 m^3 that were a part of the recirculating system. In experiment I, 102 fish individuals were placed into each tank (approximate initial stock biomass 2.5 kg/m^3; Table 1), in experiment II there were 94 individuals (approximate initial stock biomass 10 kg/m^3; Table 2). The water flow in both experiments was maintained at constant

Table 1. Growth, condition factor, size variation and feed conversion ratio of juvenile pikeperch fed in excess at different frequencies (one or three meals or continuous feeding) (average values of three replications ± SD)

Specification	Experimental groups		
	one meal	three meals	continuous feeding
Initial body weight (g)	4.9^A (± 0.05)	4.8^A (± 0.08)	4.7^A (± 0.08)
Final body weight (g)	16.2^A (± 1.70)	19.5^A (± 0.93)	18.7^A (± 0.20)
Body weight gain – DGR (g/day)	0.27^A (± 0.04)	0.35^A (± 0.02)	0.33^A (± 0.01)
Specific growth rate – SGR (%/day)	2.45^A (± 0.34)	2.45^A (± 0.05)	2.42^A (± 0.05)
Initial biomass (kg/m^3)	2.49^A (± 0.03)	2.45^A (± 0.04)	2.39^A (± 0.04)
Final biomass (kg/m^3)	8.18^A (± 0.84)	9.50^A (± 0.38)	9.47^A (± 0.03)
Biomass gain (kg/m^3)	5.69^A (± 0.82)	7.05^A (± 0.34)	7.07^A (± 0.07)
Initial condition factor – *K*	0.83^A (± 0.01)	0.83^A (± 0.01)	0.83^A (± 0.00)
Final condition factor – *K*	0.75^A (± 0.02)	0.77^A (± 0.00)	0.77^A (± 0.00)
Initial body weight coefficient of variation – Cv_{BWi} (%)	32.5^A (± 2.17)	30.9^A (± 2.05)	30.9^A (± 0.52)
Final body weight coefficient of variation – Cv_{BWf} (%)	36.4^A (± 1.25)	37.8^A (± 0.03)	36.0^A (± 1.80)
Cv_{BWf}/Cv_{BWi}	1.12^A (± 0.04)	1.22^A (± 0.08)	1.17^A (± 0.04)
Feed conversion ratio – FCR	1.39^A (± 0.11)	1.18^A (± 0.02)	1.17^A (± 0.02)

Data on the same rows marked with the same letter index do not differ significantly statistically ($P > 0.05$)

4.00 (±0.01) l/min. The water temperature was 22.2 (±0.04)°C. The total ammonia nitrogen concentration (TAN = NH_4^+-N + NH_3-N) at the inflow did not exceed 0.10 (±0.01) mg TAN/l while at the outflow it did not exceed 0.16 (±0.01) mg TAN/l. The oxygen concentrations at the inflow and outflow were 7.99 (±0.07) mg O_2/l and 6.07 (±0.14) mg O_2/l, respectively. The nitrite concentrations (NO_2-N) in the outflowing water did not exceed 0.03 (± 0.01) mg NO_2-N/l. The fish were exposed to a 24L : 0D photoperiod, and the light intensity at the tank surface was 40 to 80 lux.

Feed and feeding. The fish were fed NUTRA commercial trout diets manufactured by TROUVIT (Nutreco Aquaculture, Holland). Three granulate sizes were used during the experiments – NUTRA 0 (0.6–1.4 mm), NUTRA 1 (1.7 mm), NUTRA T (2.2 mm). The feed type was switched during a three-day adaptation period when a 50:50 mix of feeds was used. According to the manufacturer's data, the feed contained 54% protein, 18% fats, 8% carbohydrates, and digestible energy 19.5 MJ/kg. The feed was delivered with an automatic band feeder (4305 FIAP, Fish Technic Gmbh, Germany).

The feed ration in experiment I (feeding in excess) was in the range of 5.0% (beginning of the experiment) to 3.5% of fish biomass (final day of rearing). The amount of consumed feed was checked daily when the tanks were cleaned. This permitted feeding the fish only slightly in excess (feed loss in the tank was 30–50 granules). In experiment II, a restricted feeding regime was applied that ranged from 1.0 to 0.8% of the fish biomass. The distinguishing factor between both experimental groups was the frequency at which feed was delivered throughout the daily cycle. Three experimental variants were applied in which the fish were fed once daily for three hours (12:00 to 15:00), three times daily (11:00–12:00, 19:00–20:00, 02:00–03:00), or continuously for 19 hours daily (09:00–04:00). Each feeding variant was tested in three replications (3 × 3).

Procedure of collecting data and statistical analyses. Measurements of fish individuals (body weight, BW ± 0.1 g, total length, TL ± 0.1 cm) were taken at the beginning of each experiment and at two-week intervals throughout rearing. The fish were anaesthetized in a 1.0 ml/l PROPISCIN (IFI Olsztyn) solution (Kazuń and Siwicki, 2001). The biomass of the fish in each tank was determined weekly by weighing (±1.0 g) the entire stock in a container with the known water volume. Collected data were used to calculate:

Table 2. Growth, condition factor, size variation and feed conversion ratio of juvenile pikeperch fed restricted rations at different frequencies (one or three meals or continuous feeding) (average values of three replications ± SD)

Specification	Experimental groups		
	one meal	three meals	continuous feeding
Initial body weight (g)	20.8^A (± 0.71)	21.0^A (± 0.67)	21.0^A (± 0.28)
Final body weight (g)	36.9^A (± 0.17)	37.2^A (± 0.73)	38.0^A (± 0.86)
Body weight gain – DGR (g/day)	0.29^A (± 0.02)	0.29^A (± 0.00)	0.30^A (± 0.01)
Specific growth rate – SGR (%/day)	1.01^A (± 0.07)	1.00^A (± 0.02)	1.04^A (± 0.02)
Initial biomass (kg/m^3)	9.94^A (± 0.26)	10.08^A (± 0.32)	9.92^A (± 0.35)
Final biomass (kg/m^3)	17.35^A (± 0.08)	17.46^A (± 0.08)	17.48^A (± 0.01)
Biomass gain (kg/m^3)	7.42^A (± 0.35)	7.38^A (± 0.24)	7.57^A (± 0.23)
Initial condition factor – *K*	0.77^A (± 0.04)	0.78^A (± 0.01)	0.77^A (± 0.01)
Final condition factor – *K*	0.71^A (± 0.00)	0.72^A (± 0.00)	0.73^A (± 0.01)
Initial body weight coefficient of variation – Cv_{BWi} (%)	35.2^A (± 2.56)	36.5^A (± 1.62)	38.2^A (± 5.17)
Final body weight coefficient of variation – Cv_{BWf} (%)	37.0^A (± 4.43)	45.0^A (± 3.91)	41.5^A (± 4.17)
Cv_{BWf}/Cv_{BWi}	1.05^A (± 0.05)	1.23^B (± 0.05)	1.09^{AB} (± 0.04)
Feed conversion ratio – FCR	0.82^A (± 0.04)	0.83^A (± 0.03)	0.81^A (± 0.02)

Data on the same rows marked with the same letter index do not differ significantly statistically ($P > 0.05$)

– daily growth rate,
 DGR (g/day) = $(BW_2 - BW_1)/\Delta t$
– specific growth rate,
 SGR (%/day) = $100 (\ln BW_2 - \ln BW_1)/\Delta t$
– condition coefficient, $K = 100 (BW)/TL^3$
– coefficient of variability of body weight on the initial (Cv_{Bwi}) and final (Cv_{BWf}) day of the experiment, Cv_{BW} (%) = 100 (SD/BW)
– feed conversion ratio, FCR = TFS/(FB – IB)

where:

BW_1, BW_2 = initial and final body weight (g)
Δt = rearing period (days)
TL = total length (cm)
SD = standard deviation of the average body weight
IB and FB = initial and final stock biomass (g)
TFS = total feed supply (g)

The results were analyzed statistically by the STATISTICA PL program. One-way analysis of variance (ANOVA) was applied. Tukey's test was applied when statistically significant differences between groups were confirmed ($P \leq 0.05$). Prior to statistical analyses percentage data were transformed by the *arcsin* function.

RESULTS

Experiment I: effect of feeding frequency on the results of pikeperch rearing – feeding in excess

Feeding frequency was not found to have a significant effect on the growth rate of juvenile pikeperch that were fed in excess ($P > 0.05$, Table 1). The lowest daily growth rate (DGR) was observed in the fish fed once daily. In comparison with the group that was fed three times daily, in which the highest DGR was noted, this increase was 22.9% lower but the difference between the groups was statistically insignificant ($P = 0.09$). This was due to large variations in the growth rates of fish in different tanks that were fed once daily (replications) (Table 1). The feeding schedule was not found to influence the intra-group coefficient of variability of body weight (Cv_{BW}). The value of this indicator increased during rearing in all experimental groups. The quotient of the final and initial values of the Cv_{BW} coefficients (Cv_{BWf}/Cv_{BWi}) was in the range of 1.12 (one feed ration) to 1.22 (three feed rations), while the difference between the groups was statistically insignificant ($P > 0.05$; Table 1). The feed efficiency was lowest in the fish fed once daily. However, the difference between the groups was statistically insignificant ($P = 0.07$, Table 1).

Experiment II: effect of feeding frequency on the results of pikeperch rearing – restricted feeding

The frequency of feeding did not have a significant effect on the values of the majority of analyzed zootechnical parameters (body weight, stock biomass, condition factor, feed conversion ratio; $P > 0.05$; Table 2). The feeding schedule was not found to have a significant effect on the final values of Cv_{BW}. The value of Cv_{BW} in all groups increased during rearing. The lowest increase in the value of Cv_{BW} (1.8%) was noted in the group fed once daily while the highest increase (8.5%) was observed in the groups that received feed in three rations. In effect, the average values of the quotient Cv_{BWf}/Cv_{BWi} calculated for subsequent experimental groups were statistically significant ($P < 0.05$; Table 2).

DISCUSSION

The feeding frequency applied in our experiment (one or three rations or continuous feeding) did not affect the growth rate or condition of the juvenile pikeperch. The lowest values of these zootechnical parameters were calculated in the group of fish fed one ration daily, although the differences between the groups were not statistically significant. It is important that this factor was not found to influence either the groups fed in excess (experiment I) or those fed under a restricted regime (experiment II). The insignificant effect the feeding frequency had on the juvenile pikeperch in the second experiment could have resulted from an insufficient restriction of the feeding regime. It should be added, however, that the applied restriction of the feeding regime (1.0–0.8% stock biomass) was lower than that considered to be restricted in earlier studies conducted on the material of a very similar size (approximate initial BW 25 g; Zakęś et al., 2003). The lowest daily feed ration applied in the cited study was 1.2% of the stock biomass, and, in comparison with the other experimental variants (feed rations of 1.6 and 2.0% of stock biomass), it resulted in significantly lower values of the majority of analyzed parameters.

A review of the available literature indicates that the effect of feeding frequency on fish growth varies considerably. In order to provide for the maximum growth rate in salmonids, one to three rations daily are sufficient to feed them to satiation (Jobling, 1983a; Ruohonen et al., 1998), while other species such as the African catfish, *Clarias lazera*, achieve the maximum growth rate when fed continuously (Hogendoorn, 1981). Even in closely related species from the same salmonid family such as Arctic charr, *Salvelinus alpinus*, and rainbow trout, *Oncorhynchus mykiss*, the effect of feeding frequency can differ diametrically. An improvement in the Arctic charr growth rate was observed when the fish were fed at a higher frequency (8 rations versus 32; Linnér and Brännäs, 2001). However, a decrease in feeding frequency improved the growth rate of rainbow trout. A study by Alanärä (1992) also confirmed that frequent feeding with an automatic feeder had a negative effect on rainbow trout. This species exhibits a rapid increase in activity during feeding; this may suggest that frequent feeding is a stress factor that elicits great expenditures of energy thus reducing the fish growth (Alanärä, 1992). Arctic charr, however, do not react as spontaneously or aggressively and feeding is definitely calmer (Brännäs and Alanärä, 1992). Observations of the pikeperch feeding behaviour indicate that this species is calm and is not aggressive even when a restricted feeding regime is applied. The behaviour of this species possibly implies that the feeding frequency does not influence the zootechnical parameters analyzed in this study. It should be remembered that the feeding schedule could determine the growth rate of fish both directly and indirectly (e.g. by lowering water quality). Single ration feeding produces a substantial, short-term decrease in water quality that can be a significant stress factor (Giberson and Litvak, 2003). The maximum ammonia excretion and oxygen consumption and fluctuations in these parameters in the daily feeding cycle when one ration is delivered quickly can be significantly higher than when feed is delivered more frequently. This was confirmed in European perch, *Perca fluviatilis*, (Zakęś and Demska-Zakęś, 2002) and in pikeperch (Zakęś, 1999).

Fish reared under intensive conditions display varying degrees of feeding intensity at various times of the day depending on the natural daily rhythms of the given species. This phenomenon was observed in Atlantic salmon during continuous feeding (Kadri et al., 1997). Other studies indicate that fish are highly adaptable and adjust their natural daily activity pattern in captivity according to the feeding schedule applied (Wang et al., 1998). To date, no research has been conducted to determine the effect of feeding time (time of the day) on the results of pikeperch rearing. Considering that in the wild this species feeds most actively at dusk (Craig, 2000), such an effect cannot be ruled out. It should be noted that, for example, in comparison with walleye, *Sander vitreus*, pikeperch is more flexible and actively feeds during the day (Craig, 2000). In the present study, the effect of the time of the day when feed was delivered might be significant, especially in fish that were fed once daily (feeding time 12:00–15:00). However, since the applied feeding schedule did not significantly affect growth rate, among other indicators, it can be assumed that this species adapts relatively easily to controlled rearing conditions, including the feeding schedule. It is worth emphasizing that in our experiment twenty-four hour lighting was applied (at a low light intensity of 40–80 lux), and this has a positive effect on the pikeperch behaviour (Zakęś, unpublished data).

Fish that are fed less frequently can adapt to such conditions by consuming larger amounts of feed during each feeding. If such a schedule is applied for a longer period, this can lead to increased gut capacity and to hyperhagia (Jobling, 1982; Ruohonen and Grove, 1996). Fish that are fed more frequently consume a larger amount of feed; however, when the intervals between meals are short, the food passes through the digestive tract more quickly, resulting in less effective digestion (Liu and Liao, 1999). This is why determining the optimum feeding frequency (number of rations and the interval between them) is of such practical importance. The effectivity of feed utilization (feed conversion ratio) by juvenile pikeperch did not depend on the feeding frequency applied in the present study. This indicates that the effectivity of feed utilization was not influenced by the feed ration or particularly by the feeding time in fish that were fed once. Nor was the time interval between subsequent feedings (three ration regime) found to influence it. Studies conducted on salmonid fishes indicated that an hour of feeding was sufficient for the fish to eat to satiation (e.g. Elliott, 1975). In the present study, the fish were fed for three hours (one feed ration) or three times for one hour (three feed rations). Thus, it can be assumed that the applied feeding schedule met the nutritional requirements of juvenile pikeperch. Studies of walleye (Phillips et al., 1998), Atlantic sturgeon, *Acipenser oxyrinchus* (Giberson and Litvak, 2003), and sunfish hybrids (female green sunfish, *Lepomis cyanellus* × male bluegill, *L. macrochirus*) (Wang et al., 1998) also showed that the feeding frequency did not affect the feed conversion ratio.

The feeding frequency did not have a significant effect on body weight variations within the juvenile pikeperch groups. Nor was it found to increase the phenomena of hierarchy and domination within the fish stocks. It is important that this refers to both experiments in which the daily feed rations differed significantly (in excess and restricted feeding). It is recognized that the increased feeding competition, as manifested by, among other phenomena, the establishment of a hierarchy within the stock, is especially apparent when feed is limited (e.g. McCarthy et al., 1992; Jobling, 1995). The feeding schedule applied in our investigations did not, however, have an effect on the variation in juvenile pikeperch size (the value of the coefficient Cv_{BW}). This might indicate that the pikeperch do not exhibit strong stock domination or hierarchy. This hypothesis was confirmed by earlier studies in which, among other factors, the effect of the daily feed ration size on the results of rearing was tested. But in this study significant differences between the groups were noted in the growth rate, condition, and chemical composition of the fish, no differences were determined in the final Cv_{BW} coefficient (Zakęś et al., 2003). The feeding frequency was not found to have a significant effect on the values of the body weight variability coefficient in walleye (3 to 30 feed rations daily; BW = 28.2 g; Phillips et al., 1998) or in Atlantic salmon fed at frequencies of 3, 9 or 27 rations daily (average BW depended on the experiment – 225–1 218 g; Thomassen and Fjæra, 1996). It should be emphasized that in the present study the coefficient of body weight variability was highly differentiated in the replication of each experimental group. The effect of feeding frequency – Cv_{BW} was characteristic of each rearing tank. Therefore the average values of the coefficient Cv_{BW} did not differ significantly statistically. In this case, the so-called "tank effect" might come into play here (Dwyer et al., 2002).

The degree of domination that occurs within a stock can be determined by its density. If this factor is modelled properly, then the phenomena of feed competition and domination can be reduced in a fish stock (Jobling and Baardvik, 1994). In a study of the effect of feeding frequency on Arctic charr Jobling (1983b) reported that decreasing the feeding frequency of fish kept at reduced stocking densities lowered their growth rate and increased intra-group body weight variability. The application of a high stocking density reduced the level of antagonistic behaviour, which led to more effective feeding. It resulted in improved growth rate and reduced stock heterogeneity (Jobling and Baardvik, 1994). The stocking density used in the present study should be considered as low (from 2.5 to 17.5 kg/m^3). In the light of the studies cited above, the stocking densities used in the present study could cause increased antagonism among the fish. It should be emphasized that the point feed delivery method with the automatic feeder used in the present study created advantageous conditions for dominant individuals to monopolize the feed (Jobling, 1994).

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