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RESEARCH ARTICLE

Impact of feed ration on growth, feed conversion, and variation in body weights of juvenile pike, *Esox lucius* L., reared in a recirculating aquaculture system

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Abstract. The aim of the study was to determine the impact of different feed rations on growth rate, feed conversion, and variation in body weights in juvenile pike, *Esox lucius* (L.), cultured in a recirculating system. Three different feed rations were used in the experiment: 0.5% (group L), 0.8% (group O), and 1.1% (group H) of fish biomass. The fish in each group were fitted with Carlin tags and classified according to size as individuals that were small (class S) with a mean body weight of 63.0 g, medium (class M) at 90.7 g, and large (class L) at 137.2 g. After eight weeks of culture, the fish from group O had the highest mean body weight. The final body weight in this group was 7% higher than that in group H and 22.5% higher than that in group L. Differences were also noted among groups with regard to daily (DGR) and specific (SGR) growth rates in body weight and in the protein efficiency ratio (PER). The results indicate that the best culture effects of pike weighing a mean of 100 g and held at a water temperature of 22.5°C were obtained with a daily feed ration of 0.8% of the fish biomass. This ration did not result in increased pike size variation, and it permitted obtaining the greatest increases in body mass in each size group.

Keywords: feeding, pike, body weight increase, culture, predatory fish, closed recirculating system

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Introduction

Pike, *Esox lucius* (L.), is an important species in many aquatic systems. As a predator, it plays a key sanitation function in natural lakes as it clears them of weak and diseased fish. They feed most often on small fish of little value thus improving the structure of the ichthyofauna. Pike is also a species used to counteract the impact of excessive water eutrophication; by removing herbivorous fish, pike permits better development of zooplankton that filters water and removes excessive phytoplankton that leads to improved water transparency (Brylińska 2000, Gulati and van Donk 2002, Craig 2008). It is also a very popular fish among recreational fishers (McMahon and Bennett 1996, Paukert et al. 2001) and commercial fishers.

Despite legal size limits, reproduction conservation measures, and annual stocking in some waters, the numbers of pike in Polish rivers and lakes are declining. The causes of this are intense catches of this species (fisheries, recreational, poaching) and deteriorating conditions for reproduction and the development of juvenile forms (Szczerbowski 1993, Ciepielewski 1997). This is why stocking management is playing an increasingly important role. Of the various pike stocking material production methods, culture under controlled conditions using

commercial feed is becoming increasingly important. Pike is one of the most difficult fish species to culture under artificial conditions. These difficulties are rooted mainly in the cannibalistic tendencies of pike (Wolnicki and Górny 1997, Kucska et al. 2005).

The effects of intense pike culture are determined by many factors including the quality and quantity of feed. This factor can impact pike growth rates and fish size variation within groups (phenomena of domination and stock hierarchy). From a practical point of view, it is very important to determine the optimal feeding conditions for limiting size variation within groups. Pike is a predatory fish that often exhibits strong interactions among individuals. The phenomenon of competition, domination, and hierarchization in fish stocks intensifies when space or food are limited. Studies performed on salmonid fishes indicated that restrictive feeding contributes to size differentiation among individuals (Alanärä and Brännäs 1993). When this happens, some individuals can monopolize feed and consume it in quantities that fully meet their dietary needs, while the majority of the fish either consume feed in small amounts or not at all. This leads to starvation and weight loss (McCarthy et al. 1992, Kadri et al. 1996). As periods of food restriction lengthen, the size differentiation of the fish becomes more pronounced. Knowledge of the nutritional requirements of a given species (feed composition, feeding frequency, optimum ration) is one of the fundamental elements required for developing culture techniques. The aim of study was to determine the impact feed rations had on growth, feed conversion ratio, and body size differentiation of juvenile pike cultured in a recirculating system.

Materials and methods

The experimental material was juvenile pike obtained from artificial reproduction and initial rearing at the Department of Sturgeon Fish Breeding in Pieczarki, Inland Fisheries Institute in Olsztyn. The duration of the experiment was 56 days. The initial mean body weight of the pike was 97.0 ± 1.5 g, and the total length was 26.3 ± 0.2 cm. The fish were divided into three groups of 15 individuals each that were fed three different feed rations: 0.5% (group L), 0.8% (group O), and 1.1% (group H) of the fish biomass in the tank. Each feeding variant was done in three replicates. Carling tags were fitted on the dorsal fins of all the fish in each group, and the fish were classified according to size, as follows: small individuals (class S) with body weights of 63.0 g (size class 50-75 g), medium (class M) – 90.7 g (size class 80-100 g), and large (class L) – 137.2 (size class 110-150 g). Each class comprised 5 individuals.

The experiment was conducted in a recirculating system of plastic tanks with working volumes of 1.0 m^3. Each of the tanks was covered with 5 mm plastic mesh to prevent the fish from leaping out. During the experiment the fish were fed E-2 P Stella feed manufactured by Nutreco (France). The granules were 4 mm, and the feed contained 42% protein, 22% fat, and 16% carbohydrates. The digestible energy of the feed used was 20 MJ kg^{-1}. The feed was delivered by automated band feeders for 18 h per day from 12:00 to 06:00. Every morning the tanks were cleaned of waste products and unconsumed feed. During cleaning, observations were made of fish condition and mortality.

The water flow through the tank was maintained at 12 l min^{-1}. The water temperature was 22.5 ± 0.9°C. Oxygen concentration at the tank outflow was higher than 6.1 mg O_2 l^{-1}, and the water pH was 7.7 ± 0.1. Measurements of these parameters were performed with a Cyber Scan 5500 (Eutech Instruments, USA). The level of ammonia nitrogen (TAN = NH_4^+-N + NH_3-N) at the tank outflow did not exceed 0.22 mg CAA l^{-1}, while that of nitrite did not exceed 0.12 mg NO_2- l^{-1}. These parameters were determined with a Carl Zeiss 11 spectrophotocolorimeter (Germany) (Hermanowicz et al. 1999). These physicochemical parameters were measured at least once weekly.

In order to determine the fish growth rates and condition, feed coefficients, and daily feed rations, measurements were taken every seven days of individual fish body length and total length (± 1 mm) and body weight (± 0.1 g). The fish were tagged and measured after they had been anesthetized with

Propiscin (active agent etomidate, Kazuń and Siwicki 2001) at a concentration of 1 ml l^{-1} water. During measurements, the number of fish that exhibited signs of having been bitten was noted.

The data collected was used to calculate the values of the following culture indexes:

- daily growth rate, DGR (g d^{-1}) = (final body weight (g) – initial body weight (g)) × culture $period^{-1}$ (days);
- specific growth rate, SGR (% d^{-1}) = 100 × (ln final body weight (g) – ln initial body weight (g)) × culture $period^{-1}$ (days);
- body weight coefficient of variation, CV (%) = 100 × (body weight standard deviation (g) × mean $body\ weight^{-1}$ (g));
- condition factor, (CF) = 100 × (body weight (g) × body length SL^{-3} (cm));
- stock survival, M (%) = 100 × (final number (individuals) × $initial\ number^{-1}$ (individuals));
- feed conversion ratio, FCR = weight of feed delivered (g) × (final stock biomass (g) – initial stock biomass (g))$^{-1}$;
- protein efficiency ratio, PER = (final fish biomass (g) – initial fish biomass (g)) × $quantity\ of\ protein\ delivered^{-1}$ (g).

Stock hierarchy stability was also calculated and expressed as the number of individuals that remained in the same size class on the initial and final days of the experiment and the fish size differentiation expressed as the ration of the final and initial values of this coefficient ($CV_k \times CV_p^{-1}$; where: CV_k – coefficient of variation final body mass, CV_p – coefficient of variation initial body mass) (Zakęś et al. 2001).

The results were analyzed statistically with Statistica 5.0 PL. Single factor analysis of variation (ANOVA) and Tukey's test (HSD) ($P \leq 0.05$) were used to determine whether differences in the mean values of culture indexes in the groups analyzed were statistically significant.

Results

Effects of feed rations

The different feed rations applied has a statistically significant impact on pike growth. After eight weeks of culture the highest body mass was noted in the fish from group O, and it was statistically significantly higher than that in the group fed the smallest feed ration in the experiment (Table 1). Differences were observed after two weeks of culture (Fig. 1). The size of the feed ration did not have a statistically significant impact on fish total length (TL) or body length (SL). The specific growth rate (SGR) was the highest in group O (0.76% d^{-1}), and the lowest in group L

Table 1
Final results of culturing pike with different feed ratrions (0.5% fish biomass (group L), 0.8% (group O), 1.1% (group H), mean values ± SD, n = 3)

Parameter	Group L	Group O	Group H
Body weight (g)	114.4 ± 8.5^{a}	147.5 ± 14.9^{b}	137.0 ± 13.1^{ab}
Total length (cm)	27.1 ± 0.6^{a}	28.6 ± 0.5^{a}	28.1 ± 0.7^{a}
Body length (cm)	24.2 ± 0.5^{a}	25.6 ± 0.5^{a}	25.1 ± 0.7^{a}
Daily growth rate (DGR g d^{-1})	0.30 ± 0.13^{a}	0.89 ± 0.28^{b}	0.70 ± 0.20^{ab}
Specific growth rate (SGR % d^{-1})	0.29 ± 0.12^{a}	0.76 ± 0.21^{b}	0.63 ± 0.14^{ab}
Protein efficiency ratio (PER)	0.63 ± 0.28^{a}	1.85 ± 0.34^{b}	1.10 ± 0.42^{ab}
Condition factor (CF)	0.79 ± 0.02^{a}	0.86 ± 0.05^{a}	0.83 ± 0.02^{a}
Feed conversion ratio (FCR)	4.33 ± 1.93^{a}	1.32 ± 0.26^{a}	2.41 ± 0.97^{a}
Body weight variation coefficient (CV_k %)	39.1 ± 5.9^{a}	33.6 ± 4.5^{a}	32.7 ± 4.7^{a}
Fish size differentiation ($CV_k \times CV_p^{-1}$)	1.17 ± 0.07^{a}	0.91 ± 0.11^{b}	0.96 ± 0.04^{b}
Survival (%)	88.9 ± 3.8^{a}	93.3 ± 6.7^{a}	95.5 ± 3.8^{a}
Stock hierarchy stability (%)	91.1 ± 7.7^{a}	77.8 ± 7.7^{a}	82.2 ± 15.4^{a}
Number of individuals bitten (%)	6.7 ± 11.5^{a}	6.7 ± 11.5^{a}	0.0 ± 0.0^{a}

Values in the same row with the same letter index do not differ significantly statistically ($P < 0.05$)

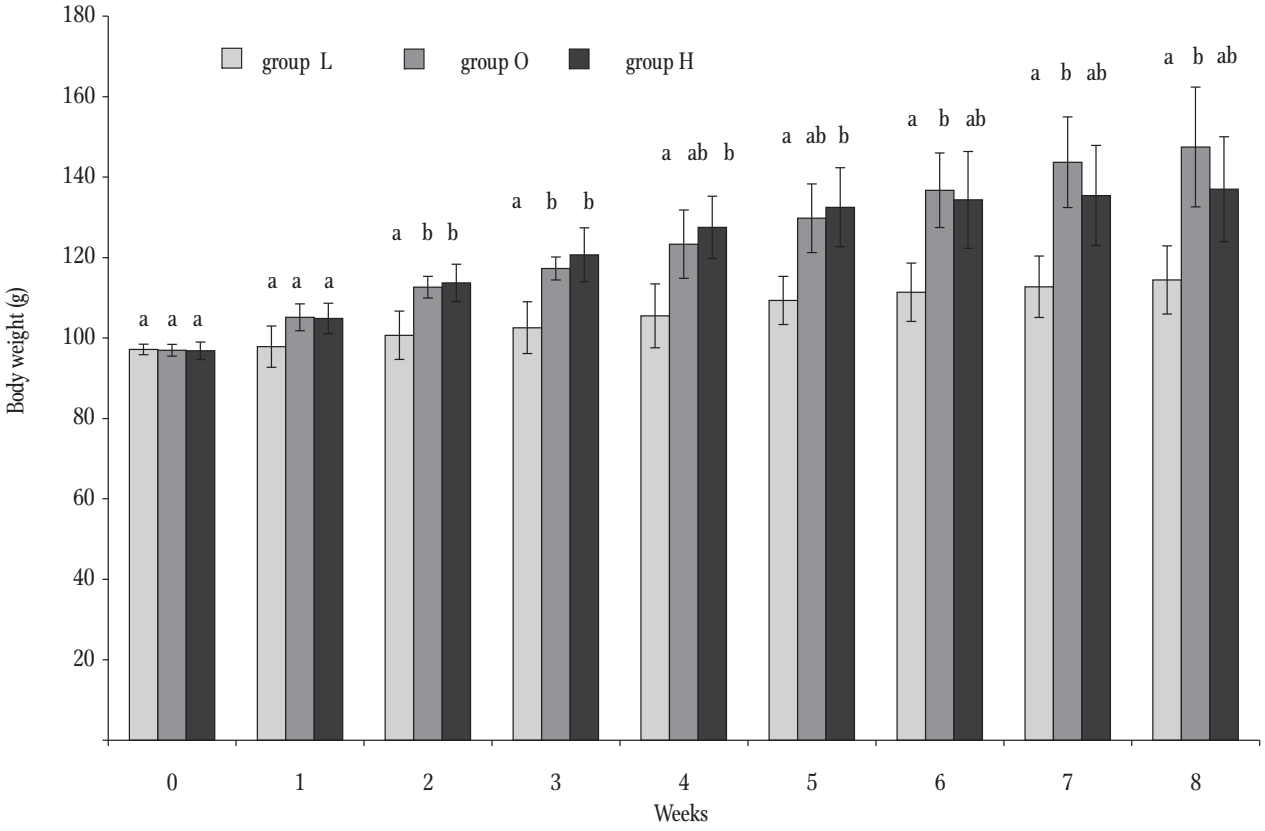

Figure 1. Body weight growth in pike fed different feed rations in subsequent weeks of culture (0.5% fish biomass (group L), 0.8% (group O), 1.1% (group H), mean values ± SD, n = 3). Values with the same letter index in the same week of culture do not differ significantly statistically ($P > 0.05$).

(0.29% d^{-1}; $P < 0.05$; Table 1). The daily growth rate (DGR) was also the highest in group O and was threefold higher than in group L ($P < 0.05$, Table 1). The feed ration did not have an impact on the values of the feed conversion ratio (FCR), which were lowest in w group O at 1.32. The protein efficiency ratio (PER) was the highest in group O at 1.85. The value in the group of pike fed the lowest feed ration (group L) was almost threefold lower, and the differences between these groups were statistically significant. The body mass variation coefficient ranged from 32.7 (group H) to 39.1 (group L). Variations between individuals ($CV_k \times CV_p^{-1}$) became more pronounced in L with a value of this parameter of over 1.0 (Table1). The application of different feed rations did not have a statistically significant impact on hierarchy stability. The highest value for this parameter was noted in group L at 91.1%. Survival fluctuated from 88.9% in group L to 95.5% in group H, and the differences among groups were not statistically significant. The percentage of individuals that had been bitten by the final day of the experiment was 6.7% in groups L and O, while in group H no such fish were noted.

Effects of size classes

The final body weight of the smallest pike increased with larger feed rations (Table 2). It ranged from 74.2 g in group L to 105.7 g in group H. The final body weight in groups O and H was statistically significantly higher than in group L. The specific growth rates and conditions coefficients were higher in these groups than in group L. No statistically significant differences in length, survival, body weight variation coefficient, size variation, or stock hierarchy stability were noted among the groups. Individuals that had

Table 2
Selected culture indexes from three size classes of pike (class S – small individuals, class M – medium individuals, class L – largest individuals) fed different feed rations (0.5% fish biomass (group L), 0.8% (group O), 1.1% (group H), mean values ± SD, n = 3)

	Class S			Class M			Class L		
Parameter	group L	group O	group H	group L	group O	group H	group L	group O	group H
Initial body weight (g)	62.4 ± 5.8^{a}	61.9 ± 5.3^{a}	64.7 ± 4.7^{a}	91.3 ± 1.1^{a}	90.3 ± 3.8^{a}	90.6 ± 4.2^{a}	137.9 ± 4.2^{a}	138.7 ± 2.5^{a}	135.1 ± 4.2^{a}
Final body weight (g)	74.2 ± 5.3^{a}	100.4 ± 4.0^{b}	105.7 ± 15.4^{b}	106.5 ± 6.0^{a}	131.8 ± 20.9^{a}	129.3 ± 5.6^{a}	168.5 ± 20.3^{a}	198.4 ± 18.0^{a}	181.7 ± 16.5^{a}
Initial body length (Lc, cm)	23.4 ± 0.7^{a}	23.3 ± 0.3^{a}	23.5 ± 0.7^{a}	25.8 ± 0.3^{a}	25.8 ± 0.3^{a}	25.7 ± 0.4^{a}	29.7 ± 0.4^{a}	29.6 ± 0.2^{a}	29.5 ± 0.3^{a}
Final body length (Lc, cm)	24.1 ± 0.5^{a}	25.5 ± 0.6^{a}	25.9 ± 1.1^{a}	26.7 ± 0.3^{a}	27.9 ± 0.9^{a}	27.8 ± 0.5^{a}	30.9 ± 0.9^{a}	30.3 ± 2.0^{a}	31.0 ± 0.4^{a}
Specific growth rate (SGR % d^{-1})	0.30 ± 0.04^{a}	0.85± 0.09^{b}	0.85 ± 0.19^{b}	0.27 ± 0.12^{a}	0.65 ± 0.26^{a}	0.62 ± 0.11^{a}	0.34 ± 0.2^{a}	0.62 ± 0.17^{a}	0.52 ± 0.11^{a}
Condition factor (CF)	0.76 ± 0.02^{a}	0.87 ± 0.05^{b}	0.83 ± 0.0^{b}	0.79 ± 0.03^{a}	0.86 ± 0.09^{a}	0.84 ± 0.02^{a}	0.79 ± 0.04^{a}	0.85 ± 0.02^{a}	0.81 ± 0.03^{a}
Body weight variation coefficient (CV_k %)	16.8 ± 5.1^{a}	17.0 ± 8.3^{a}	15.3 ± 3.2^{a}	15.0 ± 1.5^{a}	14.9 ± 1.1^{a}	15.1 ± 2.9^{a}	17.2 ± 7.4^{a}	19.6 ± 5.4^{a}	28.0 ± 14.4^{a}
Fish size differentiation ($CV_k \times CV_p^{-1}$)	1.62 ± 0.36^{a}	1.29 ± 0.45^{a}	1.97 ± 1.48^{a}	3.53 ± 1.00^{a}	2.09 ± 0.24^{a}	2.73 ± 0.41^{a}	1.01 ± 0.74^{a}	1.26 ± 0.52^{a}	1.80 ± 0.10^{a}
Survival (%)	93.3 ± 11.5^{a}	80.0 ± 20.0^{a}	100.0 ± 0.0^{a}	93.3 ± 11.5^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	80.0 ± 20.0^{a}	100.0 ± 0.0^{a}	86.7 ± 11.5^{a}
Stock hierarchy stability (%)	86.7 ± 11.5^{a}	73.3 ± 11.5^{a}	86.7 ± 11.5^{a}	86.7 ± 11.5^{a}	66.7 ± 11.5^{a}	73.3 ± 23.1^{a}	100.0 ± 0.0^{a}	93.3 ± 11.5^{a}	86.7 ± 11.5^{a}
Number of individuals bitten (%)	6.7 ± 11.5^{a}	6.7 ± 11.5^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}

Values in the same row with the same letter index do not differ significantly statistically ($P > 0.05$) within the same size classes

been bitten by other fish were noted among the smallest pike (class S). Their share did not exceed 7%, and they were noted in groups L and H, while no such specimens were noted in group H (Table 2).

The highest final body weight in class M ranged from 106.5 g in group L to 131.8 g in group O; these differences were not statistically significant. The mean specific growth rates were the lowest in respective groups among class S at 0.27% d^{-1} in group L to 0.65% d^{-1} in group O ($P > 0.05$, Table 2). No significant differences were noted among the remaining parameters: fish length, condition coefficient, body size variation, or survival. No bitten individuals were noted in class M during the experiment.

No statistically significant differences were noted in final body weight or specific growth rate (SGR) in class L at any of the feeding rations. Like the fish in class M, no significant differences in the final condition or body weight variation coefficient, fish length, size variation or survival was noted among the largest individuals. No bitten fish were noted in this class.

The final values of the condition coefficient were higher than at the beginning of the experiment in all size classes. The maximum values were noted in the fish from group O (Table 2). As fish body weight increased, the values of the specific growth rate (SGR) decreased, and only in the group fed the lowest feed ration (group L) was the value of this coefficient in class L higher (0.34% d^{-1}) than it was among the smallest specimens (class S) of this group (0.30% d^{-1}).

Discussion

The size of the feed ration had a statistically significant impact on some parameters of juvenile pike culture. The fish fed the ration of 0.8% of fish biomass exhibited the best growth. The larger feed ration of 1.1% of fish biomass did not result in increased fish growth (final body weight, DGR, SGR); however, the effectiveness of feed utilization fell (higher values of FCR and lower PER). The selection of the appropriate feed ration for pike is critical since this species consumes food only from the water column, and feed that falls to the bottom is not consumed and pollutes the environment. The manner in which pike consumes its feed combined with aggression among these fish is the cause of low feed utilization effectiveness. Proof of this is the high feed coefficient values obtained in the current experiment. Only in group O (daily feed ration of 0.8% biomass) was the value (1.32) of the FCR feed coefficient acceptable. Thus, it can be concluded that from the point of view of juvenile pike culture indexes this ration was the optimal one at the temperature of 22.5°C.

The quantity of available feed is one of the most important factors impacting size variation in and interactions among fish during culture. This can be manifested in the creation of hierarchy in groups of cultured fish with dominant and subordinate individuals. The formation of hierarchies can have a range of consequences. Individuals with subordinate status in groups can develop chronic stress; studies of salmonids indicated that such individuals had elevated levels of plasma cortisol (Sloman et al. 2000, 2001, 2002). Such individuals also exhibit lower growth rates (Abbott and Dill 1989) and greater susceptibility to disease (Pottinger and Pickering 1992). Pike do not form aggregations in the natural environment, and individuals tend to inhabit separate territorial areas. Under culture conditions these fish are held at much higher densities that cause significant changes in behavior.

The stock hierarchy created among the pike was stable. One of the factors that contributed to this was the limited access to feed, and in the group of fish fed the most restrictive feed ration over 91% of the fish were in the same size class at the end of the experiment. When all the size classes are taken into consideration, the most stable was the group of the largest individuals as they retained their dominant position in the group regardless of the feed ration. The greatest changes in stock hierarchy stability occurred in class M, the individuals of which shifted to either to the higher class L or the lower class S.

An indication of the existence of hierarchies in groups of cultured pike was also the instances of injury caused by aggressive individuals that resulted in losses. This phenomenon is often observed during

controlled fish culture (Baras et al. 2000). The first bitten pike was noted after the first week of the experiment, and the greatest increase in this phenomenon was noted in the fifth week of culture. Bodily injuries sustained by mutual aggression occurred mainly in the groups fed the lowest feed rations and among the smallest individuals (class S). Similar observations were reported in the culture of wels catfish, *Silurus glanis* L., fed different feed rations (Zakęś et al. 2001). In this experiment, intensified aggression was only noted in the group of fish that was fed restricted rations. According to the authors, this was a reaction to dietary stress stemming from limited access to feed. In the current study, injured fish were noted in groups L and O.

The impact of feed ration was also noted in changes of the body weight variation coefficient (CV) which is an indicator of stock heterogeneity. Only in the group fed the smallest feed ration (group L) was an increase noted in the product of the final and initial values of this coefficient ($CV_k \times CV_p^{-1}$), which indicates increasing variation in fish size. This contributed to more intense domination and hierarchization, and it could be why the least effective feed utilization was noted in this group. Confirmation of the existence of strong hierarchy in group L is also the fact that in this group larger individuals had higher mean specific growth rates than did medium and small individuals, but with increased fish body weight the values of these indicators decrease.

The optimum daily feed ration of 0.8% is relatively low in comparison to that fed other fish species such as pikeperch held under similar conditions (temp. 22°C, body weight 55 g) the feed ration of which was 1.5% of the stock biomass (Zakęś 2002), and a similar ration (0.9%) was fed to perch, the growth potential of which is significantly lower than that of pike (Zakęś and Demska-Zakęś 2005). This give pause for thought since larval and juvenile stages of pike are characterized by very high growth rates and feed consumption (Szczepkowski 2009). Presumably, the tendency toward lesser feed consumption is linked to strong behavioral changes observed in further pike culture that are indicated by frequent attempts by the fish to escape from the culture tanks (Szczepkowski 2009). This phenomenon was observed during the current experiment, and the culture tanks had to be securely covered to prevent this. It is interesting that pike most frequently attempted to escape from tanks in which the feed ration was small (group L), but they were noted to attempt this less frequently in group H in which the feed ration was the highest. This suggests that reduced access to feed is a strong stress agent in pike cultured on commercial feed.

The results of the experiment indicate that the lowest pike feed ration (0.5%) increased food competition. This resulted in increased fish size variation. The optimal daily feed ration for juvenile pike with a body weight of approximately 100 g cultured as a temperature of 22.5°C is 0.8% of fish biomass.

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References

Abbott J.C., Dill S.C. 1989 – The relative growth of dominant and subordinate juvenile steelhead trout (*Salmo gairdneri*) fed equal rations – Behaviour 108: 104-113.

Alanärä A., Brännäs E. 1993 – A test of the individual feeding activity and food size preference in rainbow trout using demand feeders – Aquacult. Int. 1: 47-54.

Baras E., Ndao S., Maxi S.Y.J., Jeandrain L., Thomé J.P. Vandevalle P., Mélard C. 2000 – Sibling cannibalism in dorada under experimental conditions. I. Ontogeny, dynamics, bioenergetics, of cannibalism and prey selectivity – J. Fish Biol. 57: 1001-1020.

Brylińska S. 2000 – Freshwater Fish of Poland – Wyd. PWN, Warszawa, 521 p. (in Polish).

Ciepielewski W. 1997 – Intensified pike conservation – order of the day – Komun. Ryb. 3: 4-6 (in Polish).

Craig J.F. 2008 – A short review of pike ecology – Hydrobiologia 601 1: 5-16.

Gulati R.L., van Donk E. 2002 – Lakes in the Netherlands, their origin, eutrophication and restoration: state of the art review – Hydrobiologia 478 1: 73-106.

Hermanowicz W., Dojlido J., Dożańska W., Koziorowski B., Zerbe J. 1999 – Physicochemical testing of water and sewage – Wyd. Arkady, Warszawa: 71-91 (in Polish).

Kadri M.F., Huntingford N.B., Metcalfe N.B., Thorpe J.E. 1996 – Social interactions and the distribution of food among one-sea-winter Atlantic salmon (*Salmo salar*) in a sea cage – Aquaculture 139: 1-10.

Kazuń K., Siwicki A.K. 2001 – Propiscin – a safe new anesthetic for fish – Arch. Pol. Fish. 9: 183-190.

Kucska B., Müller T., Sari J., Bodis S., Bercsenyi S. 2005 – Successful growth of the pike fingerlings (*Esox lucius* L.) on pellet at artificial condition – Aquaculture 246: 227-230.

McCarthy I.L., Carter C.L., Houlihan L.F. 1992 – The effect of feeding hierarchy on individual variability in daily feeding of rainbow trout, *Oncorhynchus mykiss* (Walbaum) – J. Fish Biol. 41: 257-263.

McMahon T.E., Bennett L.H. 1996 – Walleye and northern pike: boost or bane to Northwest Fisheries? – Fisheries 21: 6-11.

Paukert C.P., Klammer J.A., Pierce R.B., Simonson T.L. 2001 – An Overview of Northern Pike Regulations in North America – Fisheries 26: 6-13.

Pottinger T.G., Pickering A.L. 1992 – The influence of social interaction on the acclimation of rainbow trout, *Oncorhynchus mykiss* (Walbaum) to chronic stress – J. Fish Biol. 41: 435-447.

Sloman K.A., Gilmour K.S., Metcalfe N.B., Taylor A.C. 2000 – Does socially induced cortisol elevation in rainbow trout cause chloride cell proliferation? – J. Fish Biol. 56: 725-738.

Sloman K.A., Metcalfe N.B., Taylor A.C., Gilmour K.S. 2001 – Plasma cortisol concentrations before and after social stress in rainbow trout and brown trout – Physiol. Biochem. Zool. 74: 383-389.

Sloman K.A., Montpetit C.J., Gilmour K.S. 2002 – Modulation of catecholamine release and cortisol secretion by social interactions in the rainbow trout, *Oncorhynchus mykiss* – Gen. Comp. Endocrinol. 127: 136-146.

Szczepkowski S. 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.

Szczerbowski J. 1993 – Inland fisheries – Wyd. IRS, Olsztyn: 253-258 (in Polish).

Wolnicki J., Górny W. 1997 – Effects of commercial dry diets and water temperature on growth and survival of northern pike, *Esox lucius* L., larvae – Pol. Arch. Hydrobiol. 44: 377-383.

Zakęś Z. 2002 – Impact of pikeperch size on oxygen requirements and ammonia production – Komun. Ryb 2: 13-16 (in Polish).

Zakęś Z., Demska-Zakęś K. 2005 – Oxygen consumption and ammonia excretion by Eurasian perch (*Perca fluvatilis* L.) reared under optima thermal conditions – Arch. Pol. Fish. 13: 251-258.

Zakęś Z., Szkudlarek S., Czerniak M., Ulikowski L. 2001 – Feed rations and size differentiation in wels catfish cultured in recirculating systems – Komun. Ryb. 6: 12-16 (in Polish).