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Impact of selected abiotic and biotic factors on the results of rearing juvenile stages of northern pike *Esox lucius* L. in recirculating systems

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Abstract. The aim of this study was to determine the impact of selected parameters (water temperature, light intensity, feed ration and granulation size, daily feeding period, stocking density, tank shape, sorting, covering the rearing tanks) on the rearing indices of northern pike, *Esox lucius* L. The impact of these factors on the intensity of cannibalism was determined, as was their role at various stages of early northern pike development. The study results presented indicate that the factors that most influence the results of rearing include water temperature, the type of tank used, fish sorting, and the size of the daily feed ration. The optimal water temperature for growing juvenile specimens of northern pike is 28°C, but effective rearing can be achieved within a temperature range of 20 to 28°C. At the lower temperature, the length of the feeding period and the application of tank covers had less of an impact on the final rearing results. Lighting and feed grain had the least influence on the rearing results, which indicates that northern pike are highly flexible with regard to these parameters. The greatest problem in rearing northern pike juveniles was cannibalism, which accounted for as much as 93% of overall fish losses. During early ontogenic growth, substantial changes in behavior were noted which meant that the northern pike were increasingly sensitive to external stimuli. Behavioral changes noted during the growth of juvenile northern pike could have impacted reactions to various parameters. For example, the optimal feeding period is continuous over 24 hours in the initial rearing stage and then 12-hour feeding periods for older fish (with body weights exceeding 5 g).

Keywords: northern pike, juvenile stages, recirculating systems, biotic and abiotic factors

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1. Introduction

The northern pike, *Esox lucius* L., is widely distributed in the waters of Asia, Europe, and North America (Crossman 1996), where it is a significant species both commercially and ecologically. It is fished for its tasty, nearly bone-free meat, and annual global catches of it in the 1950-2004 period ranged from 18,300 to 44,200 tons (FAO 2006). Northern pike is also highly prized by recreational fishers (McMahon and Bennett 1996, Paukert et al. 2001), and in Polish waters northern pike is the most popular sport fishing species (Wołos and Falkowski 2006). A wider variety of methods is used to catch northern pike than other species (which are caught mainly with spinning methods), and this indicates that anglers target this species (Armand et al. 2002). This species is also popular because of its determination, the large sizes it can reach (even up to 30 kg), and the relative ease with which it is caught. The most important role of the northern pike in aquatic ecosystems, however, is ecological. As a typical predator, it feeds almost exclusively on fish (Crossman 1996, Załachowski 2000), thus impacting populations of other fish species both quantitatively and qualitatively. A large part of its diet comprises diseased and weakened fish. Northern pike can be used to limit the number of undesirable fish species (Paukert et al. 2003). By regulating the population numbers of small planktovorous fish, northern pike can also impact other trophic levels; this technique is sometimes applied in biomanipulation aimed at improving water quality parameters (Søndergaard et al. 2000, Gulati and van Donk 2002, Craig 2008).

Today's fisheries management is focusing increasingly on stocking in the widest possible sense, including developing reproduction and rearing techniques and introducing these materials into waters. This is particularly important with species that are facing strong anthropogenic pressure either indirectly from changing natural environments or directly from fishing. Most frequently, these two types of stress occur simultaneously causing disadvantageous changes in natural fish populations (Falkowski and Wołos 2007). Northern pike is under strong stress from humans (commercial and recreational fisheries and poaching), which, in concert with environmental changes, means that catches of this species have been on the decline in many countries for years, and it has become extinct in some basins (Szczerbowski 1993, Nilsson et al. 2004, Balik et al. 2006).

1.1. Thesis objectives

Various activities are undertaken to counteract negative changes occurring in northern pike populations. The most important are enforcing closed fishing seasons and minimum landing lengths, daily catch quotas, protection of spawning grounds, and stocking programs (Paukert et al. 2001). Among these, stocking management is becoming increasingly important. These efforts can achieve several basic goals: ensuring ecological safety; meeting community needs; economic justification (Mickiewicz 2006a, Arnason 2008). Stocking waters with northern pike meets all these criteria, and it has long been conducted in both open waters (lakes and rivers) and ponds (Borne 1886, Grimm 1981, Mickiewicz 2006b). Stocking is crucial in waters where natural reproduction has been disrupted by human activities (Sutela et al. 2004). This refers in particular to degraded littoral zones that offer less advantageous conditions for reproduction and larval stages. This can also lessen the effectiveness of stocking with larvae. To date, however, northern pike stocking programs have relied almost exclusively on hatchery-produced larvae or even eyed eggs. To a much lesser degree stocking material comprises older material that is obtained from extensive pond production or from pens (Ziliukiene and Ziliukas 2002). The results of these actions are largely unpredictable and fluctuate substantially from year to year depending on thermal and feed conditions at the moment when they are stocked into the natural environment as well as on other aquatic animals (Louarn and Cloarec 1997).

Strides made in the knowledge of ichthyology permit implementing effective techniques for rearing many species of fish which were considered, until recently, to be impossible, or at least very difficult, to rear under controlled conditions. These difficulties stem from a variety of issues linked to feeding, behaviors that are specific to a given species, or high environmental requirements. There is no doubt that northern pike is one of the more difficult species to rear under controlled conditions. Attempts to use commercial feed to rear northern pike were began as early as in the 1970s (Graff and Sorenson 1970, Timmermans 1979, Westers 1979). The initial rearing period of this species ends after 10 to 20 days, depending on water temperature (Wolnicki and Kamiński 1998, Ziliukiene and Ziliukas 2006), at the moment intensified cannibalism is observed. This phenomenon occurs after the larvae attain a body weight of about 100-200 mg. The possibilities of using material reared in this manner are greater because there is a longer period of time within which the right moment for stocking is chosen, which, in turn, can be adapted to the prevailing conditions in a given basin. A further step toward increasing the effectiveness of stocking might be to rear older forms (juveniles) as stocking material. This question has been posed and is still posed by many researchers; however, to date, no complex data are available that would permit developing the biotechniques for rearing this species under controlled conditions. The greatest obstacle is intense cannibalism, which is noted among northern pike under controlled rearing conditions as well as in natural waters (Wolnicki and Górny 1997, Hawkins et al. 2005, Kucska et al. 2005). The cannibalism phenomenon occurs in many species of fish, including in non-predatory species (Atencio-Garcia and Zaniboni-Filho 2006); however, it is most prevalent among fish species that naturally feed on other fish. Initial results of the current author's studies and observations (Szczepkowski et al. 1999, Szczepkowski and Szczepkowska 2003, 2006) indicate that it might be possible to limit cannibalism during juvenile northern pike rearing, but the underlying causes of this phenomenon must be identified first.

The aim of the study was to determine the impact of selected parameters (biotic and abiotic) on northern pike rearing indices, with a focus on losses caused by cannibalism and tracing the role of this in subsequent stages of the individual development of the fish. The impact of the following factors was studied: water temperature, light intensity, ration and granulation size of feed, daily feeding period, stocking density, tank shape, sorting, and the use of rearing tank covers. The knowledge obtained will also have practical applications. The initial results of the studies indicate that northern pike fry reared under artificial conditions is valuable stocking material (Szczepkowski et al. 2006b). This is why developing biotechniques for rearing northern pike juvenile stages under controlled conditions permits increasing the amount of stocking material produced and improves the state of stocks of this species in aquatic ecosystems.

2. Materials and methods

The experimental material comprised juvenile northern pike obtained through artificial reproduction conducted at the Dgał Experimental Hatchery (Dgał EH) in Pieczarki of the Inland Fisheries Institute in Olsztyn. The incubation of the eggs and the initial rearing of the larvae until they began active swimming were conducted according to methods described previously (Szczepkowski 2001, 2002, Szczepkowski et al. 2006a). The experiments were

Table 1

Characteristics of juvenile northern pike used in rearing experiments (mean values ± SD). The age of the fish at the beginning of the experiments

Experiment / groups	Initial body weight (g)	Initital body length (cm)	Initital stocking density (kg m^{-3})	Fish age (days)	Time of rearing (days)
Experiment I	5.7 ± 1.3	8.8 ± 0.7	2.01	71	21
Experiment II					
Experiment IIa	0.104 ± 0.014	2.5 ± 0.1	0.30	15	18
Experiment IIb	0.125 ± 0.030	2.6 ± 0.2	0.35	14	10
Experiment III	2.51 ± 0.35	7.2 ± 0.7	3.02	40	19
Experiment IV	0.101 ± 0.023	2.3 ± 0.3	0.35	14	12
Experiment V	0.201 ± 0.054	2.9 ± 0.3	1.03	24	11
	5.75 ± 1.29	8.8 ± 0.7	2.00	71	28
Experiment VI	0.54 ± 0.01	4.1 ± 0.1	1.03; 2.98; 4.90	25	13
Experiment VII					
stage I	0.012 ± 0.001	1.1 ± 0.0	0.24	8	14
stage II	0.23 ± 0.07	3.1 ± 0.3	0.50	27	13
stage III	3.08 ± 1.13	7.2 ± 0.7	1.00	55	13
Experiment VIII*					
group SW	1.15 ± 0.53	4.8 ± 0.7	1.14	35	13
group SM	0.74 ± 0.16	4.1 ± 0.3	1.14	35	13
group N	0.95 ± 0.39	4.5 ± 0.5	1.14	35	13
Experiment IX	0.59 ± 0.22	4.3 ± 0.5	1.48	27	13

* SW – larger fish from sorting; SM – smaller fish from sorting; N – unsorted fish.

conducted in the rearing facilities at the Dgał EH especially in these periods of individual development which were previously confirmed to be the critical stages of northern pike juvenile rearing, when the greatest losses were noted (Szczepkowski et al. 1999, Szczepkowska and Szczepkowski 2001). This also permitted determining that the length of each of the experiments (rearing) should not exceed 14 days, due to rapid growth and the highly variable sizes of the fish that could lead to a sudden increase in cannibalism. In older (and thus larger) fish, this period was longer (Table 1).

During experimental rearing, the impact of the following biotic (experiments III, IV, V, VI, VIII) and abiotic (experiments I, II, VII, IX) factors were studied:

- water temperature (three temperature variants – experiment I):
- light intensity (four levels of light intensity – experiment II);
- feed ration (three feed rations – experiment III);
- feed granulation (two feed granulation sizes – experiment IV);
- daily feeding period (three feeding periods – experiment V);
- stocking density (three stocking densities – experiment VI);
- tank shape (two tank shapes – experiment VII);
- sorting (either applied or not – experiment VIII);
- external visual stimuli (tank covers applied or not – experiment IX).

The experiments were conducted using juvenile stages aged from 14 to 71 days post-hatch (DPH); only in experiment VII were feeding northern pike larvae used (Table 1). All of the experiments were conducted in three replicates. The only exception was experiment VII, which was conducted in two replicates.

2.1. Technical conditions of the experiments

The rearing experiments were conducted in recirculating systems at the Dgał EH in 2003-2007. Most of the experiments (III-IX) were conducted in recirculating systems with a total volume of 75 m^3 equipped with a water purification system comprised of a clarifier with a volume of 31.8 m^3, eight column shelf filters (with three shelves each) lined with diatomite substrate (Kolman 1992), an oxygen generator (Oxyline ON 250 Diamond Lite S.A., Switzerland) with an oxygenation column that provided oxygen to the water. Experiments I and II were conducted in recirculating systems with a total volume of 4.1 m^3, and each system was fitted with a biological filter (CT 11 10, SDK Ostróda, Poland) filled with 160 kg of granulated polyethylene substrate (Malen E, Orlen Płock, Poland).

Water temperature during the experiments was maintained at the desired level with electronic controllers (Dixell XR 20C, Italy). The fish were reared in tanks made of artificial material with a working volume of 1.0 m^3 (ST 12 10 tanks, SDK Ostróda, Poland). Only in comparative experiment VII were the tanks round (RFT 14-06 tanks, SDK Ostróda, Poland) with a volume of 0.6 m^3.

2.2. Experimental procedure

Water quality parameters were controlled during the experiment. Water samples were taken from the outflows of the rearing tanks. The oxygen content in the water (± 0.01 mg dm^{-3}) and the pH (to 0.01) were determined with a CyberScan PCD 5500 meter (Eutech Instruments, USA). Total ammonia nitrogen CAA = NH_4^+ + NH_3 was determined by the Nesslerization method, while nitrites were determined with the sulphanilic method (Hermanowicz et al. 1999) using a Carl Zeiss 11 spectrophotometer (Carl Zeiss Jena, Germany). The physical and chemical parameters of the water during all of the experiments are presented in Table 2.

Table 2
Physical and chemical parameters of water at the outflows of tanks during experimental rearing

Experiment / groups	Water temperature (°C)	pH range	Minimum oxygen content (mg dm^{-3})	Maximum CAA = NH_4^+ + NH^3 (mg dm^{-3})	Maximum NO_2^- (mg dm^{-3})	Water flow (dm^3 min^{-1})	Light intensity (lx)
Experiment I							
Group T20	20.0	7.91 – 7.97	7.8	0.18	0.08	12.0	72.0
Group T24	24.0	7.98 – 8.03	6.5	0.25	0.21	11.6	75.6
Group T28	28.0	8.05 – 8.20	5.5	0.35	0.22	12.6	76.3
Experiment II							
Experiment IIa	21.5 ± 1.2	7.65 – 7.79	7.4	0.26	0.22	10.5	1.10; 5.66
Experiment IIb	21.5 ± 1.1	7.60 – 7.70	7.2	0.28	0.20	11.0	50; 438.8
Experiment III	19.5 ± 0.4	7.85 – 7.97	7.1	0.25	0.17	14.0	47.3
Experiment IV	18.1 ± 0.6	7.54 – 7.64	7.7	0.14	0.13	12.0	112.8
Experiment V	21.9 ± 0.5	7.80 – 7.86	7.0	0.24	0.20	13.7	55.4
	20.5 ± 0.6	7.84 – 7.88	6.9	0.14	0.06	16.2	61.0
Experiment VI	17.6 ± 1.0	8.18 – 8.28	7.6	0.22	0.20	23.8	146.5
Experiment VII							
stage I	18.4 ± 0.4	7.79 – 7.93	8.2	0.19	0.03	6; 10	58.2
stage II	18.1 ± 0.3	8.03 – 8.21	7.9	0.15	0.10	6; 10	74.7
stage III	19.5 ± 0.4	7.87 – 7.97	8.0	0.25	0.17	6; 10	69.5
Experiment VIII	20.2 ± 0.7	8.05 – 8.21	8.9	0.20	0.21	14.6	29.6
Experiment IX	18.6 ± 0.6	8.18 – 8.33	6.9	0.20	0.12	13.2	87.6

The fish were fed Nutreco (Trouv, France) commercial feeds (Table 3). As the fish grew, the pellet size was increased and the daily ration of feed was decreased (Table 4). Feed granule size was adjusted during rearing by mixing the smaller and larger feed granule sizes together for two days at a ratio of 1:1. The fish were fed around the clock except in experiment V. The feed was served with a 4305 FIAP automatic band feeder (Fischtechnik GmbH, Germany). The feed was onto the loaded into the feeders twice daily at 07:00 and 19:00. Once a day the bottoms of the tanks were cleared of fish excrement and unconsumed feed and fish deaths were noted.

In experiment I, rearing was conducted at three water temperatures: 20, 24, and 28°C (groups T20, T24, and T28; Table 2) according to methods described previously (Szczepkowski 2006). The mean fish body weight of fish used in the experiment was 5.7 g, and length of the experiment was 21 days.

Table 3
Proximal composition, energetic value, and granulation of feeds used during the rearing of juvenile northern pike – manufacturers' data

Feed	Protein (%)	Fat (%)	Carbohydrates (%)	Digestible energy (MJ kg^{-1})	Granule size (mm)
Nutra Amino Balance 3.0	55	16	8	19.0	0.4-0.7
Nutra Amino Balance 2.0	54	18	8	19.5	0.6-1.0
Nutra Amino Balance 0	54	18	8	19.5	0.8-1.4
Nutra 1	54	18	8	19.5	1.7
Nutra T	52	20	8.5	19.9	2.2
Nutra 1P Sturio	47	14	21	18.5	2.5

Table 4
Diets types and daily feed rations applied during the rearing of juvenile northern pike. The experimental groups are described in the Materials and methods section. Feed characteristics see Table 2

Experiment / groups	Fed type at beginning of experiment	Period of feeding with feed (DPH)	Initial feed ration (% biomass d^{-1})	Feed type at the end of the experiment	Period of feeding with feed (DPH)	Final feed ration (% biomass d^{-1})
Experiment I						
Group T20	Nutra T	D71 – D85	2.0	Nutra 1P Sturio	D84 – D92	2.0
Group T24	Nutra T	D71 – D85	3.0	Nutra 1P Sturio	D84 – D92	2.5
Group T24	Nutra T	D71 – D85	4.0	Nutra 1P Sturio	D84 – D92	3.0
Experiment II						
Experiment IIa	Nutra Amino Balance 2.0	D15 – D25	11.0	Nutra Amino Balance 0	D24 – D33	5.6
Experiment IIb	Nutra Amino Balance 2.0	D14 – D20	10.0	Nutra Amino Balance 0	D19 – D24	4.0
Experiment III	Nutra 1	D40 – D54	4.0; 6.0; 8.0	Nutra T	D53 – D59	3.0; 4.5; 6.0
Experiment IV						
Group N2.0	Nutra Amino Balance 2.0	D14 – D26	10.0	Nutra Amino Balance 2.0	D14 – D26	4.5
Group N0	Nutra Amino Balance 0	D14 – D26	10.0	Nutra Amino Balance 0	D14 – D26	4.5
Experiment V						
Groups S-F12, S-F24	Nutra Amino	D24 – D35	10.0	Nutra Amino Balance 0	D24 – D35	5.2
Groups L-F12, L-F18, L-F24	Balance 0 Nutra T	D71 – D85	4.0	Nutra 1P Sturio	D84 – D99	2.7
Experiment VI	Nutra Amino Balance 0	D25 – D38	6.0	Nutra Amino Balance 0	D25 – D38	3.2
Experiment VII						
stage I	Nutra Amino Balance 3.0	D8 – D14	20.0	Nutra Amino Balance 2.0	D13 – D22	11.0
stage II	Nutra Amino Balance 2.0	D27 – D34	10.0	Nutra Amino Balance 0	D33 – D40	4.2
stage III	Nutra 1	D55 – D64	4.0	Nutra T	D63 – D68	3.4
Experiment VIII	Nutra Amino Balance 0	D35 – D45	5.0	Nutra 1	D44 – D48	3.6
Experiment IX	Nutra Amino Balance 0	D27 – D36	6.0	Nutra 1	D35 – D40	3.3

In experiment II, the following light intensities were applied: 1.10 ± 0.04 and 5.66 ± 0.56 lx (groups 1 lx and 5 lx – experiment IIa) and 50.0 ± 1.1 and 438.8 ± 5.9 lx (groups 50 lx and 430 lx – Experiment IIb). Measurements were taken at the water surface in the central part of the rearing tank with an L–100 lux meter (Sonopan, Poland) that measured light to the nearest 0.001 lx up to 10 lx and to the nearest 0.01 lx over 10 lx. The experiment was conducted in a dimmed room where only artificial lighting was used. The desired light intensity was set using an electronic regulator and these levels were maintained throughout the experimental period.

In experiment III, the following initial daily feed rations were applied: 4.0; 6.0; 8.0% of fish biomass day^{-1} (groups L4, L6, L8). During the experiment, the ration was decreased gradually by 3.0, 4.5, and 6.0% of fish biomass day^{-1}. The mean fish body mass at the beginning of the experiment was 2.5 g, and the initial stocking density was 3 kg m^{-3} (Table 1).

In experiment IV, the fish were fed Nutra Amino Balance 2.0 with a granule size of 0.6-1.0 mm in the initial period (from the beginning of feeding to day 14). After the experiment proper had begun, the fish in one variant continued to receive the same feed (group N2.0), while the second group received Nutra Amino Balance 0 (group N0) feed with a larger granulation size (0.8-1.4 mm). In this experiment, the stock comprised fish aged 14 days post-hatch (DPH) with a mean body weight of 0.101 g.

In experiment V, the northern pike were fed for different lengths of time over 24-h periods: group

F24 – around the clock; group F18 – for 18 h (07:00 to 01:00); group F12 – 12 h (07:00 to 19:00). The experiment was conducted in two variants with fish of different ages and sizes (Table 1). The groups of smaller fish (24 DPH) were identified as S-F12 and S-F 24, while the older northern pike were identified as L-F 12, L-F 18, and L-F 24. Feed was loaded into the feeders at 07:00, and for the 18 and 24-h feeding variants feed was loaded again at 19:00. The feed ration was divided proportionally in these variants. In F18, 2/3 of the feed ration was served between 07:00 and 19:00, and 1/3 was served from 19:00 to 01:00, while in the 24-h feeding variant half of the feed was served between 07:00 and 19:00, while the other half was served between the hours of 19:00 and 07:00. With the younger fish the experiment lasted for 11 days, and with the larger fish for 28 days.

In experiment VI, three different initial stocking densities were applied: 1.03 kg m^{-3} (group G1); 2.98 kg m^{-3} (group G3); 4.90 kg m^{-3} (group G5). The mean body weight of the fish reared in this experiment was 0.54 g. The experiment was conducted for 13 days.

In experiment VII, two tank shapes that are widely used in hatchery-rearing facilities were tested. These were round tanks (group O) with a volume of 0.6 m^3, and square tanks (group M) with a volume of 1.0 m^3. Both were manufactured of artificial materials. The experiments were conducted in three northern pike size groups, as follows: freely swimming post-hatch larvae (stage I – mean body weight 11.5 mg) and two groups of juvenile stages (stage II – mean body weight 0.227 g and stage III – 3.08 g; Figs. 1 and 2). Stage I lasted for 14 days, while stage II and III lasted for 13 days. The stocking density in both tank shapes was identical, and the type and ration of feed (expressed as the % of the fish biomass) were also identical in both groups of tanks at the same stages of the experiment (Table 4). Water flow in the tanks was proportional to their volumes and was 6 dm^3 min^{-1} in the round tanks (group O) and 10 dm^3 min^{-1} in the square tanks (group M).

In experiment VIII, juvenile northern pike were divided after preliminary rearing into size groups using a slot sorter with a 3.6 mm slot. Two groups of fish were obtained in this way: larger (group SW) – mean body weight 1.15 g and smaller (group SM) – mean body weight 0.74 g. Some of the fish were left unsorted (group N), and the mean body weight of this group was 0.95 g. Next, fish from particular groups were stocked into separate rearing tanks so that stock biomass was identical in all the tanks at 1.14 kg m^{-3}. The experiment was conducted for 13 days (Table 1).

Experiment IX examined how larvae react to external visual stimuli and whether or not this has an impact on the results of rearing. To this aim the rearing tanks were isolated from the external surroundings by a net covering with netting manufactured from artificial materials and with a mesh bar length of 5 mm (group A). The control group (group B) was a tank without covering. The mean larvae body weight at the beginning of the experiment was 0.59 g, and the larvae were 27 DPH (D27). The remaining rearing parameters are listed in Tables 1 and 2.

Before the beginning and the end of each experiment, body length SL (± 0.1 cm) and body weight BW (± 0.01 or 0.001 g) measurements were taken. Random samples of 20 – 30 individuals were taken from each variant studied. Before the measurements, the fish were anesthetized in a solution of Propiscin (Kazuń and Siwicki 2001) at a concentration of 1 cm^3 dm^{-3}. Additionally, the total biomass was determined by weighing all the fish from a given variant (at the beginning and end of the experiments). The initial sizes and ages of the fish used in all of the experiments are presented in Table 1.

After the completion of the experiments, the following rearing indices were calculated:

$$SGR = (\ln (BW_2) - \ln (BW_1)) \times D^{-1} \times 100 \quad (1)$$

where: SGR – specific growth rate (% day^{-1}), BW_2 and BW_1 – mean body weight at the end and beginning of the experiment (g), D – rearing time (days),

$$F = 100 \times (BW \times SL^{-3}) \quad (2)$$

where: F – Fulton condition coefficient, BW – body weight (g), SL – body length (cm),

$$V = (SD \times BW^{-1}) \times 100 \quad (3)$$

where: V – variation coefficient of body weight (%), SD – standard deviation of fish body weight (g), BW – mean body weight (g),

$$FCR = F \times B^{-1} \quad (4)$$

where: FCR – feed conversion ratio, F – quantity of feed served (g), B – increase in fish biomass (g),

$$PER = (FB - IB) \times FPS^{-1} \quad (5)$$

where: PER – protein efficiency ratio, IB and FB, initial and final biomass (g), FPS – feed protein served (g)

$$S = L_k L_p^{-1} \times 100\% \quad (6)$$

where: S – survival (%), L_k – number of fish caught at the end of the experiment (indiv.), L_p – number of fish stocked at the beginning of the experiment (indiv.).

The magnitude of cannibalism (C) was calculated based on the difference between the number of fish stocked at the beginning of the experiment minus the natural mortality and the number of fish caught at the end of the experiment.

$$C = ((L_p - M - L_k) L_p^{-1}) \times 100\% \quad (7)$$

where: C – cannibalism (%), L_p – number of fish stocked at the beginning of the experiment (indiv.), M – natural mortality (indiv.), L_k – number of fish caught at the end of the experiment (indiv.). Natural mortality was designated as all the dead fish removed from the tank during the experiment regardless of the cause of death.

Northern pike larval and juvenile behavior was observed during controlled rearing. Observations were conducted for 44 days under conditions similar to those during typical rearing. The observations were begun on the day that the larvae began actively swimming, which was the eighth day after hatching (8 DPH=110°D). The fish were held in three square basins (SDK–ST 12 10 tanks) with a volume of 1 m^3. The stock numbered 20,000 individuals (at a stocking density of 20 indiv. dm^{-3}). The behavior of the fish was analyzed on subsequent days of rearing, as were their distribution in the tanks and their reactions to external stimuli. The feeding procedure applied was that described for experiments I – IX : 24-h serving of feed via an automatic band feeder manufactured by Nutreco (Trouv, France) (Table 3). The daily feed ration was 20% of the fish biomass at the moment of observations and then was gradually reduced to 3% of the biomass at the end of the experiment. The mean water temperature was 18.4 ± 1.1°C (range 16.0-20.0°C). On day 26 of rearing, the fish were divided into two groups with a 2.9 mm slot sorter. Two size groups were obtained: the smaller fish had a mean body weight of 0.31 ± 0.08 g and the larger had a mean body weight of 0.56 ± 0.13 g. The smaller fish were used in further rearing and observations, while the larger fish were separated out.

2.3. Statistical analysis

Statistical calculations were performed with Statistica 5.0 PL (StatSoft Inc.). Single factor analysis of variance (ANOVA) was applied to confirm the significance between the mean values of the rearing indices studied. Tests of significant differences among the experimental variants were performed on the basic mean values from the replicates of a particular variant. Tukey's test was used to evaluate the significance of differences, which were considered statistically significant at $P < 0.05$.

3. Results

3.1. Experiment I. Impact of temperature on juvenile northern pike rearing

Water temperature had a significant impact on the feeding of the fish from the beginning of the experiment. The fish gathered at the feeding site in groups T24 and T28 at the first feeding (32 h after stocking). In group T20, this was observed after a subsequent 24 hours. Substantially fewer fish gathered near the feeders at the lowest temperature (20°C) than they did at the higher temperatures (24 and 28°C). The slowest growing fish were those from group T20, in which the mean, final mean body weight was 11.90 g, and the difference was statistically significant in comparison with the

Table 5

Selected rearing parameters of juvenile northern pike at various water temperatures (T20 – 20°C, T24 – 24°C, T28 – 28°C) (mean values ± SD; N = 3)

	Experimental groups		
Specification	T20	T24	T28
Initial body weight (g)	5.60 ± 1.41	5.81 ± 1.28	5.82 ± 1.23
Final body weight (g)	11.90 ± 1.41^{a}	13.68 ± 1.39^{b}	14.74 ± 1.45^{b}
Daily growth rate (g d^{-1})	0.30 ± 0.07	0.37 ± 0.07	0.42 ± 0.07
Specific growth rate SGR (% d^{-1})	3.56 ± 0.59	4.05 ± 0.48	4.42 ± 0.46
Body weight variation coefficient V (%)	26.4 ± 2.7^{a}	19.4 ± 3.6^{a}	24.2 ± 3.5^{a}
Initial body length SL (cm)	8.70 ± 0.73	8.77 ± 0.65	8.82 ± 0.61
Final body length SL (cm)	11.24 ± 0.50^{a}	11.63 ± 0.44^{b}	11.60 ± 0.24^{ab}
Condition factor K	0.82 ± 0.01^{a}	0.86 ± 0.01^{ab}	0.93 ± 0.03^{c}
Survival (%)	90.2 ± 3.5^{a}	87.0 ± 3.0^{a}	98.7 ± 1.6^{b}
Cannibalism (%)	7.0 ± 1.5^{ab}	9.7 ± 2.2^{a}	0.4 ± 0.3^{b}
Natural losses (%)	2.8 ± 0.5^{ab}	3.3 ± 0.4^{a}	0.9 ± 0.6^{b}
Feed conversion ratio FCR	0.61 ± 0.05^{a}	0.70 ± 0.04^{ab}	0.71 ± 0.04^{bc}
Protein efficiency ratio PER	3.16 ± 0.13	2.86 ± 0.37	2.73 ± 0.08

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

mean body weights of the fish from groups T24 (P < 0.05) and T28 (P < 0.01; Fig. 1). No statistically significant differences were noted, however, between the mean body weights in groups T24 and T28. The variation coefficient for body weight fluctuated from 19.4 (group T24) to 26.4 (group T20), and the confirmed differences were not statistically significant (P > 0.05). The longest body length was attained by fish

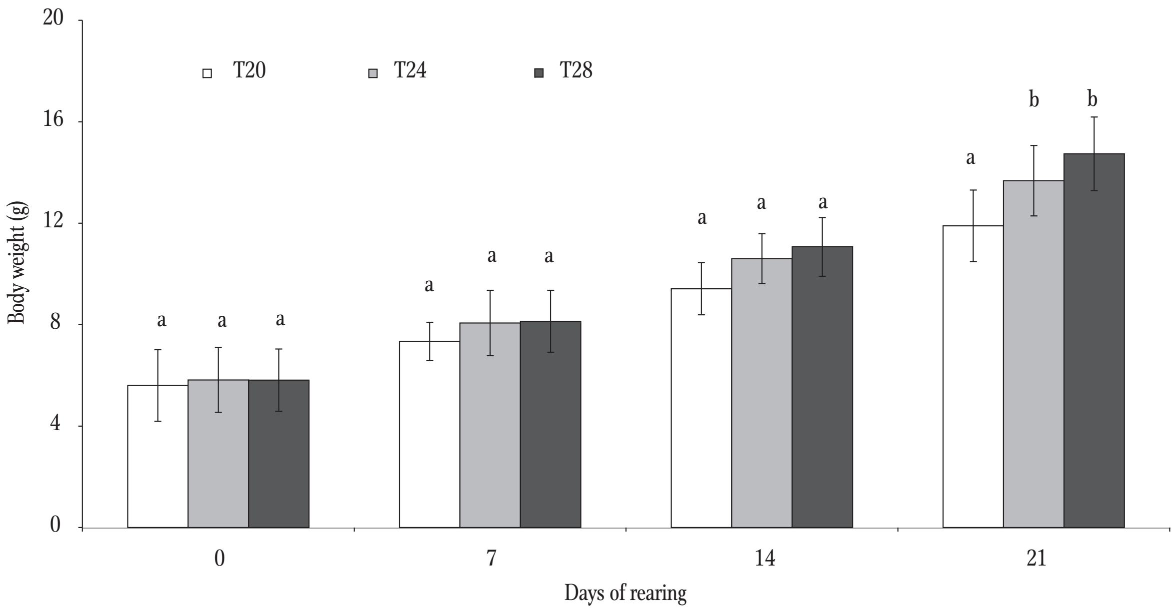

Figure 1. Growth rate of juvenile northern pike reared at different water temperatures (T20 – 20°C; T24 – 24°C; T28 – 28°C) in subsequent weeks (mean values ± SD; N = 3). Groups marked with the same letter index in the same week did not differ significantly statistically (P > 0.05).

Table 6

Selected rearing parameters of juvenile northern pike reared under different light intensity (1 or 5 lx – Experiment IIa, 50 or 438 lx – Experiment IIb) (mean values ± SD; N = 3). No significant differences were noted among the groups (P > 0.05)

	Experimental groups			
	Experiment IIa		Experiment IIb	
Specification	Group 1 lx	Group 5 lx	Group 50 lx	Group 438 lx
Initial body weight (g)	0.13 ± 0.03	0.13 ± 0.03	0.10 ± 0.01	0.10 ± 0.01
Final body weight (g)	0.44 ± 0.04	0.48 ± 0.04	1.40 ± 0.04	1.41 ± 0.07
Specific growth rate SGR (% d^{-1})	12.52 ± 0.86	13.40 ± 0.73	14.42 ± 0.16	14.45 ± 0.27
Body weight variation coefficient V (%)	28.6 ± 2.6	28.6 ± 3.0	28.5 ± 2.2	33.3 ± 8.2
Initial body length SL (cm)	2.60 ± 0.20	2.60 ± 0.20	2.47 ± 0.13	2.47 ± 0.13
Final body length SL (cm)	4.01 ± 0.14	4.09 ± 0.12	5.54 ± 0.07	5.56 ± 0.06
Condition factor K	0.67 ± 0.02	0.69 ± 0.03	0.79 ± 0.01	0.79 ± 0.00
Survival (%)	87.7 ± 0.3	86.9 ± 0.9	66.4 ± 3.5	63.1 ± 3.3
Cannibalism (%)	3.3 ± 1.0	2.2 ± 0.8	27.3 ± 3.5	28.8 ± 0.4
Natural losses (%)	9.0 ± 1.3	10.9 ± 0.3	6.3 ± 0.2	8.1 ± 1.3
Feed conversion ratio FCR	0.84 ± 0.11	0.74 ± 0.07	0.43 ± 0.00	0.46 ± 0.02
Protein efficiency ratio PER	2.27 ± 0.30	2.54 ± 0.25	4.31 ± 0.03	4.03 ± 0.19

reared at a temperature of 24°C, and the shortest at 20°C (Table 5). Differences between these groups were statistically significant (P < 0.05).

Significant differences in the values of the condition coefficient were noted in the groups analyzed (Table 5). The highest value (0.93) was noted in group T28, while the lowest value was in group T20. The most advantageous survival index values were recorded for the highest temperature group at a mean of 98.7% (Table 5). This difference was statistically significant in comparison to the other groups (P < 0.05).

The most advantageous feed conversion ratio (FCR) of 0.61 was noted in group T20, while the highest value of 0.71 was obtained in group T28 (P < 0.05; Table 5). The protein efficiency ratio (PER) declined as temperature increased, but differences were not statistically significant (P > 0.05).

3.2. Experiment II. Light intensity and the effectiveness of juvenile northern pike rearing

None of the differences in any of the rearing parameters studied in experiment IIa were statistically significant (P > 0.05). Of the northern juvenile pike groups reared at light intensities of 1 and 5 lx, it was confirmed that by the end of the experiment the fish from the second group had attained both greater lengths and body weights and exhibited a higher condition coefficient (Table 6). The size variation of the fish in groups expressed as the value of the body weight variation coefficient was identical (V = 28.6%). In turn, in group 1 lx higher survival and feed conversion ratios were achieved. Survival in both lighting variants was high at more than 86% of the initial stock, and losses to cannibalism were insignificant at 3.3% in group 1 lx and 2.2% in group 5 lx. Natural losses were higher, however, and the course of these was similar in both experimental variants. The highest losses were observed at the end of the experiment (Fig. 2).

The comparison of rearing results for juvenile pike at a stronger light intensity (Experiment IIb – 50 and 430 lx) also indicated a lack of any statistically significant differences (P > 0.05; Table 6). The survival rate at the end of the experiment was 66.4% (group 50 lx) and 63.1% (group 430 lx). Fish losses were caused primarily by cannibalism; in group 50 lx losses to cannibalism were 27.3% of the initial stock,

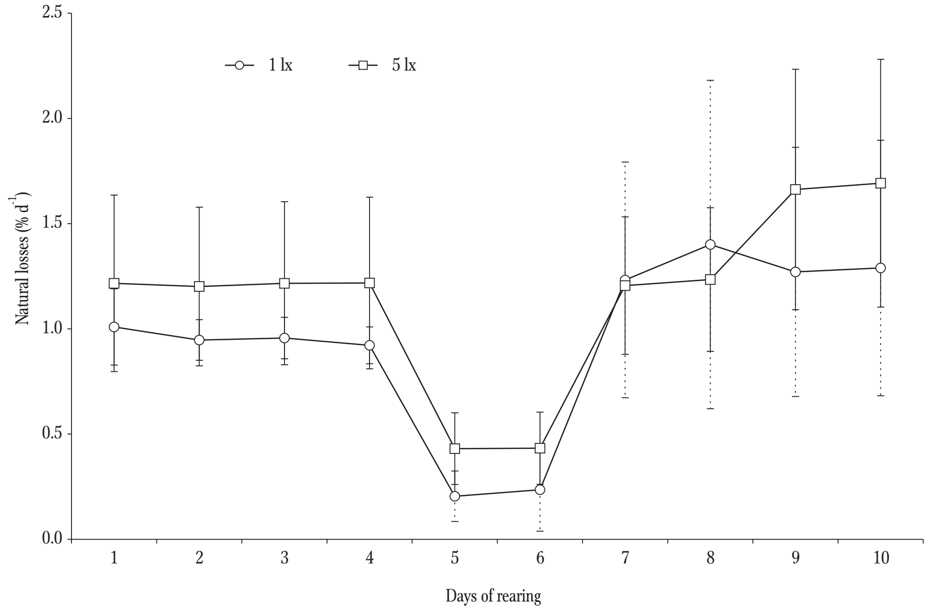

Figure 2. Course of natural losses during the rearing of juvenile northern pike at tank light intensities of 1 and 5 lx (mean values ± SD; N = 3).

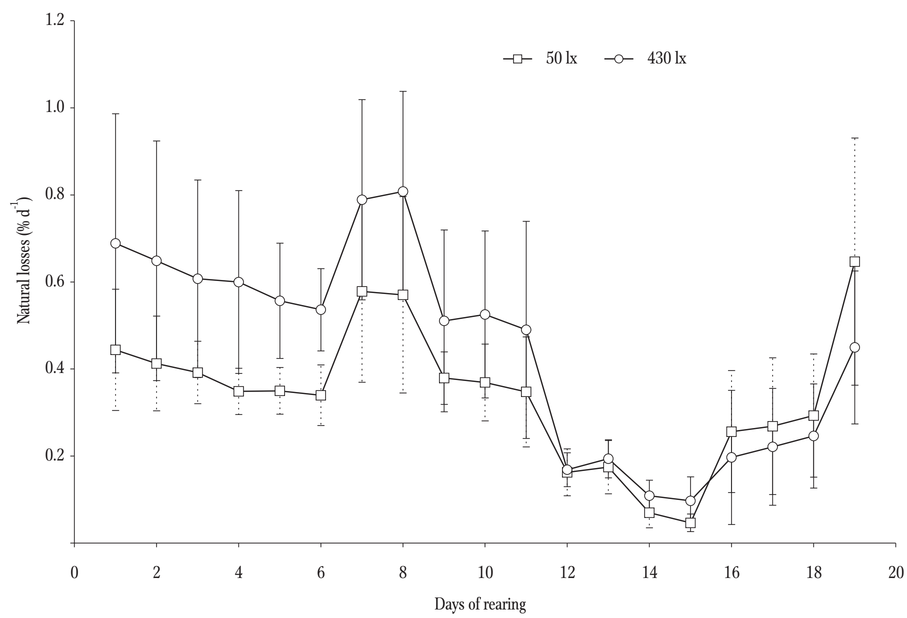

Figure 3. Course of natural losses during the rearing of juvenile northern pike at a tank light intensities of 50 and 430 lx (mean values ± SD; N = 3).

while in group 430 lx it was 28.8% of the initial stock. The course of natural losses at both light intensities was similar (Fig. 3). The greatest losses were noted on day 8 of rearing, but a sharp decline was noted after this day until day 14. After this, losses increased again, and among the dead fish were many individuals that bore traces of attacks by other fish.

3.3. Experiment III. Impact of feed ration on the results of northern pike rearing

Applying higher rations of feed (group L8) did not result in faster weight gain during the rearing period. By the end of the experiment, the fish in group L6 had attained the greatest weight increase at 6.11 g;

Table 7
Selected rearing parameters of juvenile northern pike fed different feed rations (group L4 – 4% of stock biomass, group L6 – 6% of stock biomass, group L8 – 8% of stock biomass) (mean values ± SD; N = 3)

	Experimental groups		
Specification	L4	L6	L8
Initial body weight (g)	2.51 ± 0.35	2.51 ± 0.35	2.51 ± 0.35
Final body weight (g)	5.54 ± 0.43	6.11 ± 0.59	5.61 ± 0.55
Specific growth rate SGR (% d^{-1})	4.16 ± 0.42	4.66 ± 0.52	4.21 ± 0.51
Body weight variation coefficient V (%)	21.4 ± 2.7	23.1 ± 0.8	18.2 ± 1.0
Initial body length SL (cm)	5.51 ± 0.39	5.51 ± 0.39	5.51 ± 0.39
Final body length SL (cm)	8.71 ± 0.21	8.93 ± 0.29	8.66 ± 0.29
Condition factor K	0.83 ± 0.01	0.85 ± 0.00	0.85 ± 0.01
Survival (%)	82.9 ± 3.6^a	82.1 ± 2.8^a	95.5 ± 1.8^b
Cannibalism (%)	14.4 ± 3.0^a	14.0 ± 6.5^a	2.3 ± 3.1^b
Natural losses (%)	2.7 ± 0.8	3.9 ± 1.3	2.2 ± 0.8
Feed conversion ratio FCR	0.63 ± 0.03^a	0.81 ± 0.16^b	0.95 ± 0.09^b
Protein efficiency ratio PER	6.91 ± 0.08^a	5.13 ± 0.39^b	3.97 ± 0.19^c

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

however, there were no statistically significant differences among the groups (P > 0.05; Table 7).

The mean daily weight gain in group L6 was the highest at 4.66% day^{-1}. Survival of the fish in the groups compared ranged from 82.1 (group L6) to 95.5% (group L8). Survival in group L8 was statistically significantly higher than the other groups (P < 0.01; Table 7). There were no statistically significant differences among the studied groups in fish deaths from natural causes, which ranged from 2.2 (group L8) to 3.9% (group L6). In all the groups, losses to natural causes were observed in the first period of rearing (Fig. 4).

Significant differences in the losses to cannibalism were noted among the groups. In groups L4 and L6 they were 14.4 and 14.0%, but in group L8, the

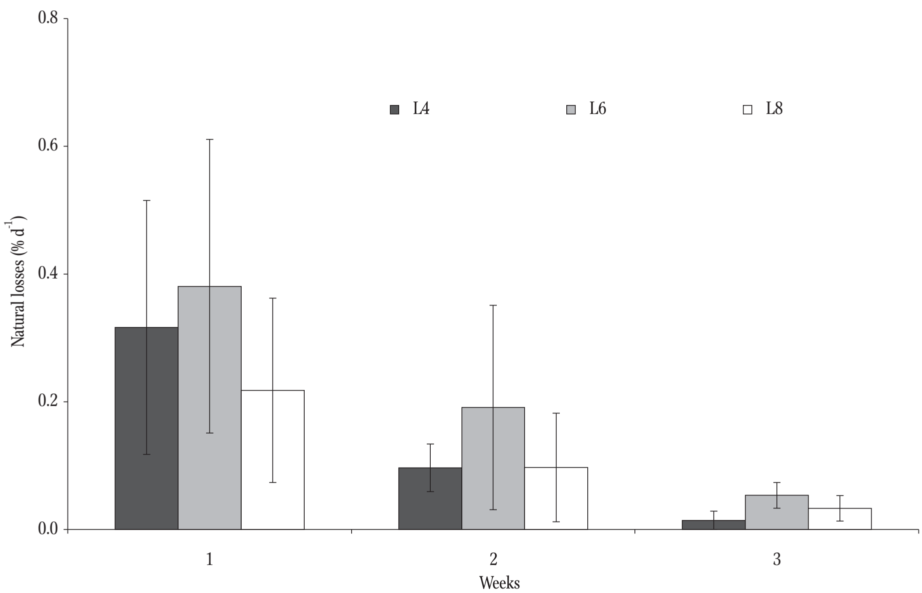

Figure 4. Course of natural losses during the rearing of juvenile northern pike on different feed rations (group L4 – 4% of stock biomass; group L6 – 6% of stock biomass; group L8 – 8% of stock biomass) (mean values ± SD; N = 3).

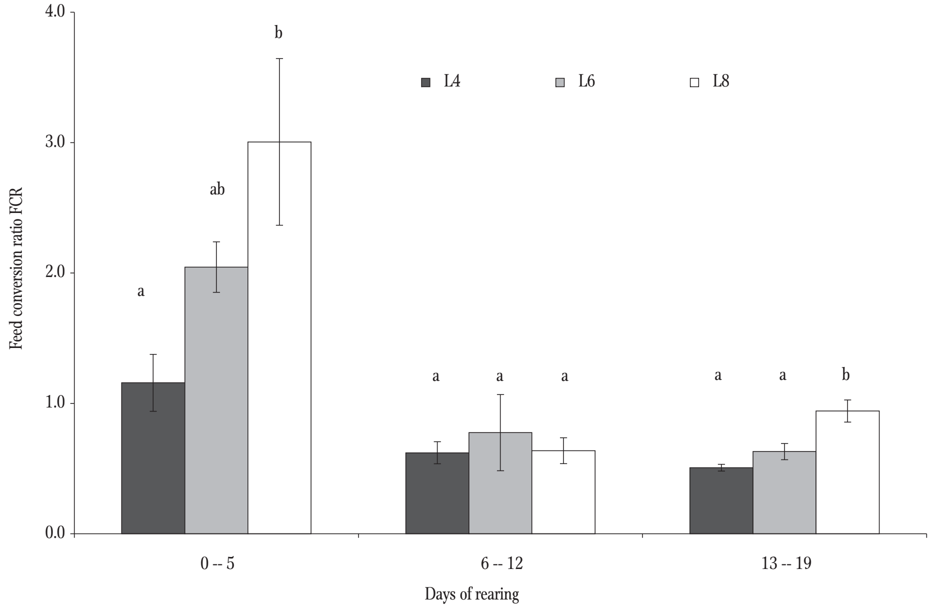

Figure 5. Feed conversion ratio (FCR) in subsequent periods of rearing juvenile northern pike fed different feed rations (group L4 – 4% of stock biomass; group L6 – 6% of stock biomass; group L8 – 8% of stock biomass;) (mean values ± SD; N = 3). Groups marked with the same letter index in the same week did not differ significantly statistically (P > 0.05).

one that received the largest feed ration, it was lower at 2.3% (P < 0.05). The magnitude of the feed conversion ratio increased with increasing feed rations; in group L4 it was 0.63, and in group L8 it was 0.95. The differences between group L4 and the other groups was statistically significant (P < 0.05). The initial period immediately after the fish had been stocked into the tanks had the greatest impact on the final FCR since their feed utilization in this period was substantially weaker, especially in group L8 (Fig. 5). As the feed ration increased, the protein efficiency ratio (PER) decreased. In the group fed the smallest feed ration the value of this coefficient was 6.91, and in the group fed the largest ration it was 3.97 (Table 7). The differences between these groups were highly statistically significant (P < 0.001).

3.4. Experiment IV. Impact of feed granulation size on the results of northern pike rearing

The final mean body weights and lengths of juvenile northern pike fed feed of different granulation sizes (groups N2.0 and N0) did not differ significantly statistically (P > 0.05; Table 8). The greatest differences

Table 8

Selected rearing parameters of juvenile northern pike fed of differing pellet sizes (group N2.0 – 0.6-1.0 mm, group N0 – 0.8-1.4 mm) (mean values ± SD; N = 3). No significant differences were noted among the groups (P > 0.05)

	Experimental groups	
Specification	N 2.0	N0
Initial body weight (g)	0.101 ± 0.023	0.101 ± 0.023
Final body weight (g)	0.68 ± 0.03	0.73 ± 0.03
Specific growth rate SGR (% d^{-1})	15.91 ± 0.32	16.41 ± 0.39
Body weight variation coefficient V (%)	25.3 ± 1.0	29.5 ± 4.5
Initial body length SL (cm)	2.3 ± 0.3	2.3 ± 0.3
Final body length SL (cm)	4.3 ± 0.0	4.3 ± 0.1
Condition factor K	0.88 ± 0.01	0.89 ± 0.01
Survival (%)	65.0 ± 1.0	63.7 ± 3.4
Cannibalism (%)	26.2 ± 3.2	23.9 ± 2.9
Natural losses (%)	8.8 ± 2.8	12.4 ± 2.6
Feed conversion ratio FCR	0.48 ± 0.01	0.48 ± 0.02
Protein efficiency ratio PER	3.84 ± 0.07	3.85 ± 0.15

were noted in the body weight variation coefficients. While it was higher (29.54%) in group N0, it did not differ significantly statistically in relation to group N2.0, in which it was 25.29% (Table 8). Survival, intensity of cannibalism, and natural losses in both groups were similar. In group N2.0, they were 65.0, 26.2, and 8.8%, respectively, and in group N0 they were 63.7, 23.9, and 12.4%, respectively. The values for feed and protein utilization were also similar in both groups (Table 8), with mean values in both groups of the FCR coefficient at 0.48 and of the PER at 3.84 (group N2.0) and 3.85 (group N0).

3.5. Experiment V. Impact of feeding period on the results of rearing juvenile northern pike

Variation in the length of the feeding period over the course of a 24-hour period (groups S-F12 and S-F24) did not have an impact on juvenile growth (24 DPH) of northern pike since the final body weight, body length, or mean daily weight increases did not differ statistically significantly between the groups (P > 0.05). The survival of juvenile pike was higher in group S-F24 at 62.4%, which was statistically significantly higher than that in group S-F12 (P < 0.05). Higher survival was the result of fewer losses to cannibalism, which were 14.9 and 31.0%, respectively, in groups S-F24 and S-F12 (P < 0.05). The natural losses in the two groups were similar at 22.7 in S-F24 and 18.7% in S-F12 (Table 9).

The losses occurred at different times in the two groups. There was a sharp increase in fish deaths in group S-F12 at the start of the experiment (Fig. 6), while losses in group S-F24 were low at the beginning of rearing and remained at a similar level nearly throughout the experiment. The FCR coefficient in group S-F24 was 0.69 and was significantly statistically lower than in group S-F12, for which it was 0.87 (P < 0.01; Table 9). The longer feeding period had an impact on the degree of protein utilization. The PER coefficient was statistically significantly higher in group S-F24 at 2.50 in comparison to group S-F12, in which is was 1.83 (P = 0.0093).

Table 9

Selected rearing parameters of juvenile northern pike (age 24 DPH) fed for different lengths of time during the day (group S-F12 – 12 h d^{-1}; group S-F24 – 24 h d^{-1}) (mean values ± SD; N = 3)

Specification	Experimental groups	
	S-F12	S-F24
Initial body weight (g)	0.201 ± 0.054	0.201 ± 0.054
Final body weight (g)	0.822 ± 0.049	0.759 ± 0.025
Specific growth rate SGR (% d^{-1})	12.77 ± 0.53	12.07 ± 0.30
Body weight variation coefficient V (%)	25.9 ± 4.9	26.7 ± 6.6
Initial body length SL (cm)	2.9 ± 0.3	2.9 ± 0.3
Final body length SL (cm)	4.44 ± 0.08	4.37 ± 0.04
Condition factor K	0.93 ± 0.01	0.95 ± 0.01
Survival (%)	50.3 ± 2.6[a]	62.4 ± 0.4[b]
Cannibalism (%)	31.0 ± 2.2[a]	14.9 ± 4.5[b]
Natural losses (%)	18.7 ± 1.0	22.7 ± 4.1
Feed conversion ratio FCR	0.87 ± 0.01[a]	0.69 ± 0.04[b]
Protein efficiency ratio PER	1.83 ± 0.04[a]	2.50 ± 0.14[b]

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

The length of the feeding period had a slight impact on the growth of the older fish (Table 10).

At the end of the experiment, the fish that had been fed around the clock (group L-F24) attained the highest mean body weight 13.16 g. The mean body weight in the other groups was slightly lower at 12.68 g (group L-F18) and 12.83 g (group L-F12) (P > 0.05). The values of specific growth rate (SGR) were also very similar and ranged from 3.74 (group L-F18) to 3.90% day^{-1} (group L-F24). Substantially higher differences were noted in the survival of the northern pike. The highest survival at 99.2% was confirmed in group L-F12, while the lowest, at 89.6%, was noted for group L-F24 (P < 0.05). The values of the FCR coefficients were similar (Table 10) in that the lowest was noted in group L-F12 (0.98) and the highest was noted in group L-F24 (1.16) (P > 0.05). The degree of protein utilization in older (71 DPH) northern pike decreased as daily feeding period was lengthened (Table 10).

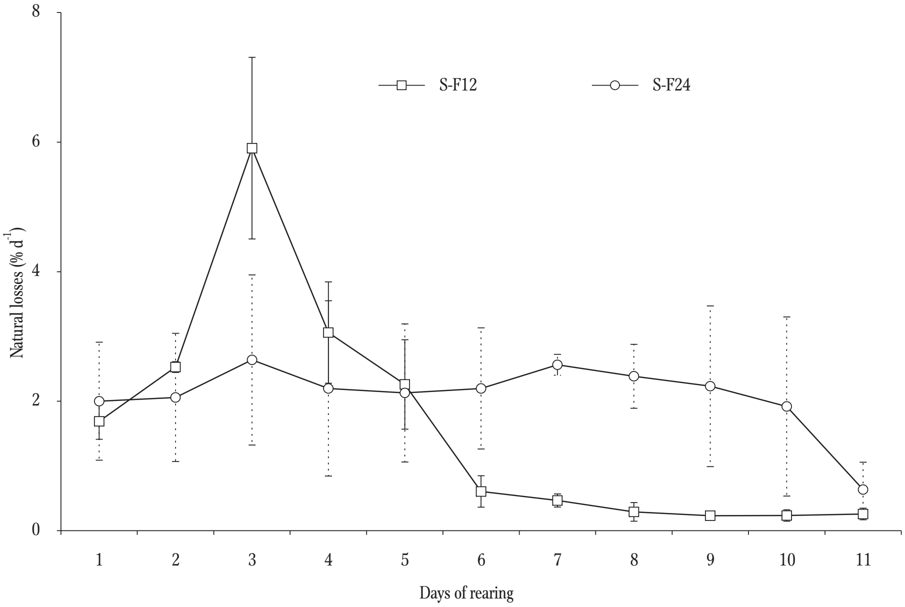

Figure 6. Course of natural losses during the rearing of juvenile northern pike (age 24 DPH) fed for different lengths of time over the day (group S-F12 – 12 h d^{-1}; group S-F24 – 24 h d^{-1}) (mean values ± SD; N = 3).

Table 10

Selected rearing parameters of juvenile northern pike (age 71 DPH) fed for different time periods during the day (group L-F12 – 12 h d^{-1}; group L-F18 – 18 h d^{-1}; group L-F24 –24 h d^{-1}) (mean values ± SD; N = 3)

	Experimental groups		
Specification	L-F12	L-F18	L-F24
Initial body weight (g)	5.68 ± 0.77	5.78 ± 0.64	5.80 ± 0.34
Final body weight (g)	12.83 ± 0.93	12.68 ± 0.66	13.16 ± 0.67
Specific growth rate SGR (% d^{-1})	3.88 ± 0.34	3.74 ± 0.25	3.90 ± 0.24
Body weight variation coefficient V (%)	20.7 ± 0.4	24.7 ± 2.3	21.5 ± 2.1
Initial body length SL (cm)	8.74 ± 0.36	8.75 ± 0.36	8.81 ± 0.09
Final body length SL (cm)	11.63 ± 0.25	11.52 ± 0.16	11.68 ± 0.15
Condition factor K	0.81 ± 0.02	0.82 ± 0.01	0.81 ± 0.01
Survival (%)	99.2 ± 0.6[a]	96.4 ± 3.5[ab]	89.6 ± 3.9[b]
Cannibalism (%)	0.4 ± 0.3[a]	3.0 ± 1.8[ab]	9.5 ± 2.3[b]
Natural losses (%)	0.4 ± 0.1	0.6 ± 0.2	0.9 ± 0.1
Feed conversion ratio FCR	0.98 ± 0.08	1.08 ± 0.06	1.16 ± 0.09
Protein efficiency ratio PER	1.96 ± 0.09	1.78 ± 0.05	1.67 ± 0.07

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

Table 11

Selected rearing parameters of juvenile northern pike reared at different stocking densities (group G1 – 1.0 kg m^{-3}; group G3 – 3.0 kg m^{-3}; group G5 – 5.0 kg m^{-3}) (mean values ± SD; N = 3)

	Experimental groups		
Specification	G1	G3	G5
Initial body weight (g)	0.52 ± 0.12	0.54 ± 0.14	0.54 ± 0.12
Final body weight (g)	1.83 ± 0.02	1.86 ± 0.07	1.79 ± 0.16
Specific growth rate SGR (% d^{-1})	9.65 ± 0.08	9.43 ± 0.31	9.18 ± 0.72
Body weight variation coefficient V (%)	19.4 ± 2.8	25.1 ± 1.5	22.9 ± 1.7
Initial body length SL (cm)	4.1 ± 0.3	4.2 ± 0.4	4.1 ± 0.3
Final body length SL (cm)	5.72 ± 0.03	5.75 ± 0.07	5.72 ± 0.17
Condition factor K	0.97 ± 0.00[a]	0.96 ± 0.01[ab]	0.94 ± 0.01[b]
Survival (%)	80.9 ± 1.2	87.2 ± 3.6	83.7 ± 4.5
Cannibalism (%)	15.1 ± 1.1	10.2 ± 3.7	13.1 ± 4.3
Natural losses (%)	4.0 ± 0.7	2.6 ± 0.2	3.2 ± 0.9
Feed conversion ratio FCR	0.51 ± 0.01	0.48 ± 0.02	0.54 ± 0.01
Protein efficiency ratio PER	3.60 ± 0.06	3.86 ± 0.18	3.41 ± 0.05

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

3.6. Experiment VI. Stocking density and the results of rearing juvenile northern pike

Fish growth decreased as stocking density increased. The SGR ranged from 9.65 to 9.18% per day^{-1} (G1 and G5, respectively), but the differences observed were not statistically significant ($P > 0.05$). The final body weights and lengths of the fish in the experimental groups were similar ($P > 0.05$; Table 11).

The survival of the juvenile northern pike in all the experimental groups was high, with the highest in group G3, and the lowest in group G1 (Table 11). Fish losses were primarily due to cannibalism, which ranged from 10.2 to 15.1% (G3 and G1, respectively). Natural losses were also similar in all groups ($P > 0.05$) and ranged from 2.6 to 4.04% (G3 and G1, respectively). Natural losses in all of the groups were the highest immediately after the fish were stocked into the tanks and at the end of the experiment (Fig. 7). The FCR fluctuated from 0.48 in group G3 to 0.54 in group G5. As stocking density increased, the values of condition coefficient K decreased at 0.97 in group G1 to 0.94 in group G5 ($P < 0.05$).

3.7. Experiment VII. Impact of tank shape on the rearing indices of juvenile northern pike

Substantial behavioral differences were observed in the fish in the tank shapes tested. In group M (square tanks) the fish gathered in large aggregations mainly in the surface layer of the water. In group O (round tanks) the juvenile northern pike were more evenly distributed over the entire surface and tended not to form larger aggregations. Increases in fish body weight and length in both groups was similar. In stages I and III of rearing, the fish from group M attained higher body weights, while in stage II the fish from group O did (Table 12).

The differences were statistically significant in stages I ($P < 0.01$) and II ($P < 0.05$) of rearing. In stage I greater body lengths were attained by the fish in group M ($P < 0.01$), and in stages II and III by the fish in group O ($P > 0.05$). The relative daily specific growth rate (SGR) decreased by about 18.0 in stage I to about 4.5% day^{-1} in stage III. In stages I and III the SGRs were higher in group M, and in stage II in group O.

Tank shape had a significant impact on larval and juvenile northern pike survival (Table 12). Group M (square tanks) survival was higher in all

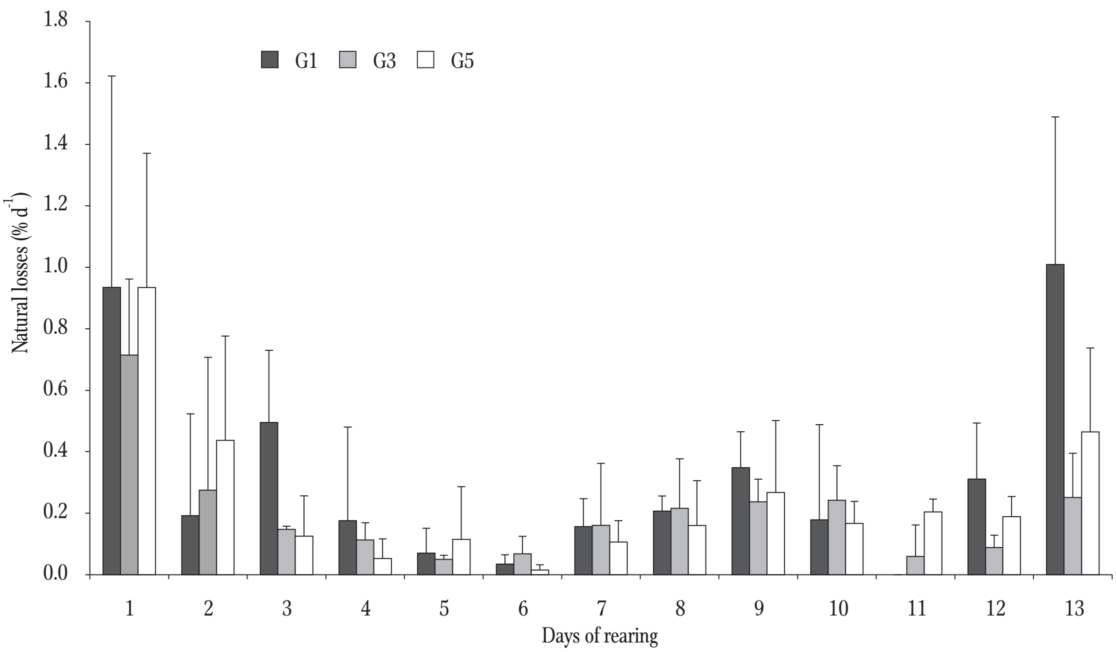

Figure 7. Course of natural losses of juvenile northern pike reared at different stocking densities (group G1 – 1.0 kg m^{-3}; group G3 – 3.0 kg m^{-3}; group G5 – 5.0 kg m^{-3}) (mean values ± SD; N = 3).

Table 12
Growth, condition coefficient, and feed conversion ratio of northern pike larvae and juvenile stages reared in differently shaped tanks (group O – round; group M – square tanks) (mean values ± SD; N = 2)

		Experimental groups	
Specification	Experiment stage	O	M
Final body weight (g)	I	0.120 ± 0.003[a]	0.140 ± 0.016[b]
	II	1.36 ± 0.17[a]	1.22 ± 0.01[b]
	III	5.42 ± 0.46	5.52 ± 0.04
Final body length SL (cm)	I	2.47 ± 0.07[a]	2.58 ± 0.09[b]
	II	5.56 ± 0.16	5.39 ± 0.01
	III	8.67 ± 0.22	8.60 ± 0.12
Body weight variation coefficient V (%)	I	22.4 ± 0.3	20.7 ± 3.6
	II	26.9 ± 7.1	25.2 ± 2.8
	III	24.5 ± 5.7	20.0 ± 3.5
Specific growth rate SGR (% d^{-1})	I	17.76 ± 0.19	18.80 ± 0.83
	II	13.72 ± 0.99	12.95 ± 0.04
	III	4.33 ± 0.66	4.48 ± 0.06
Condition factor K	I	0.79 ± 0.05	0.80 ± 0.02
	II	0.77 ± 0.02	0.77 ± 0.00
	III	0.82 ± 0.00	0.86 ± 0.03
Survival (%)	I	40.8 ± 11.8	48.9 ± 9.9
	II	66.3 ± 0.5	79.7 ± 3.1
	III	85.4 ± 5.2	99.4 ± 0.3
Cannibalism (%)	I	31.1 ± 9.7	22.3 ± 3.1
	II	29.8 ± 2.1	17.1 ± 3.3
	III	13.6 ± 5.2	0.3 ± 0.2
Natural losses (%)	I	28.1 ± 2.1	28.8 ± 4.1
	II	3.9 ± 2.5	3.2 ± 0.2
	III	1.0 ± 0.0	0.3 ± 0.00
Feed conversion ratio FCR	I	1.15 ± 0.17	0.88 ± 0.19
	II	0.60 ± 0.08	0.55 ± 0.00
	III	0.96 ± 0.08	0.66 ± 0.07
Protein efficiency ratio PER	I	1.59 ± 0.23	2.12 ± 0.46
	II	3.10 ± 0.40	3.35 ± 0.03
	III	1.94 ± 0.15	2.80 ± 0.30

Data in rows with different letter indexes differ significantly statistically ($P < 0.05$).

stages, and the differences increased as did the body weights of the reared fish. The higher survival in group M was due to weaker cannibalism at 8.8, 12.7, and 13.3% at stages I, II, and III of the experiment respectively. At all stages of rearing, greater differences in fish size were noted at the end of the experiment in individuals reared in group O (Table 12).

Feed utilization by northern pike larvae and fry reared in the different groups also differed substantially (Table 12). The FCR values were lower in group M in the I and III stages of the experiment by 0.25 and 0.30, respectively, and only in stage II were similar results achieved. The protein efficiency ratio at all stages was higher in group M, but intergroup differences were not statistically significant ($P > 0.05$; Table 12).

Table 13
Juvenile northern pike rearing parameters in groups according to sorting (group SW – larger fish from sorting; group SM – smaller fish from sorting, group N – unsorted fish, group S (SW + SM) – combined larger and smaller fish from sorting (mean values ± SD; N = 3)

Specification	Experimental groups			
	SW	SM	N	S (SW + SM)
Initial body weight (g)	1.15 ± 0.53	0.74 ± 0.16	0.95 ± 0.39	0.95 ± 0.39
Final body weight (g)	3.43 ± 0.42	2.78 ± 0.29	3.67 ± 0.46	3.10 ± 0.27
Specific growth rate SGR (% d^{-1})	9.27 ± 1.39	10.08 ± 0.84	9.30 ± 0.56	9.68 ± 0.75
Body weight variation coefficient V (%)	27.1 ± 6.4	33.5 ± 7.7	23.7 ± 5.1	30.3 ± 4.7
Initial body length SL (cm)	4.8 ± 0.7	4.1 ± 0.3	4.5 ± 0.5	4.5 ± 0.5
Final body length SL (cm)	7.4 ± 0.2	6.8 ± 0.1	7.6 ± 0.2	7.1 ± 0.2
Condition factor K	0.84 ± 0.04	0.84 ± 0.03	0.82 ± 0.03	0.84 ± 0.02
Survival (%)	77.0 ± 0.5^{a}	75.5 ± 1.6^{ab}	70.1 ± 1.9^{b}	76.2 ± 0.8^{a}
Cannibalism (%)	21.9 ± 0.9^{a}	23.6 ± 1.4^{ab}	29.1 ± 2.0^{b}	22.8 ± 0.8^{a}
Natural losses (%)	1.1 ± 0.5	0.9 ± 0.3	0.8 ± 0.3	1.0 ± 0.3
Feed conversion ratio FCR	0.64 ± 0.03^{ab}	0.54 ± 0.02^{a}	0.72 ± 0.04^{b}	0.59 ± 0.03^{a}
Protein efficiency ratio PER	2.90 ± 0.12^{a}	3.43 ± 0.10^{b}	2.58 ± 0.13^{a}	3.16 ± 0.14^{a}

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

3.8. Experiment VIII. Impact of sorting juvenile northern pike on the results of rearing

The fish that had not been sorted (group N) attained higher final body weights and lengths (Table 13). The values of the condition coefficient in groups S and N were similar at 0.84 and 0.82, respectively. The indicator of variation in body weight in the experimental groups was lower in the unsorted fish, but the difference was not statistically significant. Survival was higher in the fish from group S and was 76.2%, while that from the unsorted fish was 70.1% (P < 0.05). This result stemmed from the rate of cannibalism in group N, which was nearly 7% higher. Natural losses in both groups were similar and comprised just about 1% of the initial stock. Sorting had a positive impact on the feed conversion ratio. The FCR coefficient in the fish from group S was 0.59 and was statistically significantly lower in comparison to the fish that were from group N, where it was 0.72 (P < 0.05). The protein efficiency ratio (PER) was also higher in group S (Table 13).

The analysis of the rearing indices of the remaining groups that were created by sorting (groups SW and SM) indicated that there were differences between these groups. Feed utilization expressed as the feeding coefficient was the highest in the fish from group SM at 0.54. Differences in the value of the FCR coefficient among groups SM and N was highly statistically significant (P < 0.01). The protein efficiency ratio was the highest in the group of the smallest sorted fish at a value of 3.43. In groups SW and N the values of this index were under 3 (Table 13). The difference in the PER index was statistically significant between groups SM and N (P < 0.001), as well as between groups SM and SW (P < 0.05). The value of the variation coefficient of body weight was the highest in the group of the smallest sorted fish at 33.5%. The mean values of this parameter in individual groups did not differ significantly statistically (P > 0.05).

Sorting had a significant impact on fish survival (P < 0.05). The lowest survival was noted in group N, and the highest in group SW (Table 13). Losses caused by cannibalism were lower in the sorted groups and were 21.9 and 23.6 in groups SW and SM, respectively. The differences in cannibalism

Table 14
Selected rearing parameters of juvenile northern pike reared in uncovered and covered tanks (group A – tanks covered by nets; group B – uncovered tanks) (mean values ± SD; N = 3)

	Experimental groups	
Specification	A	B
Initial body weight (g)	0.59 ± 0.22	0.59 ± 0.22
Final body weight (g)	2.66 ± 0.01[a]	2.44 ± 0.05[b]
Specific growth rate SGR (% d^{-1})	11.57 ± 0.02[a]	10.90 ± 0.15[b]
Body weight variation coefficient V (%)	19.03 ± 2.13	20.13 ± 3.10
Initial body length SL (cm)	4.3 ± 0.5	4.3 ± 0.5
Final body length SL (cm)	6.74 ± 0.04	6.62 ± 0.04
Condition factor K	0.87 ± 0.01	0.83 ± 0.00
Survival (%)	79.4 ± 0.2[a]	87.0 ± 2.3[b]
Cannibalism (%)	16.7 ± 0.3[a]	10.6 ± 2.1[b]
Natural losses (%)	3.9 ± 0.3[a]	2.4 ± 0.3[b]
Feed conversion ratio FCR	0.48 ± 0.00	0.48 ± 0.00
Protein efficiency ratio PER	3.84 ± 0.03	3.84 ± 0.05

Data in rows with different letter indexes differ significantly statistically (P < 0.05).

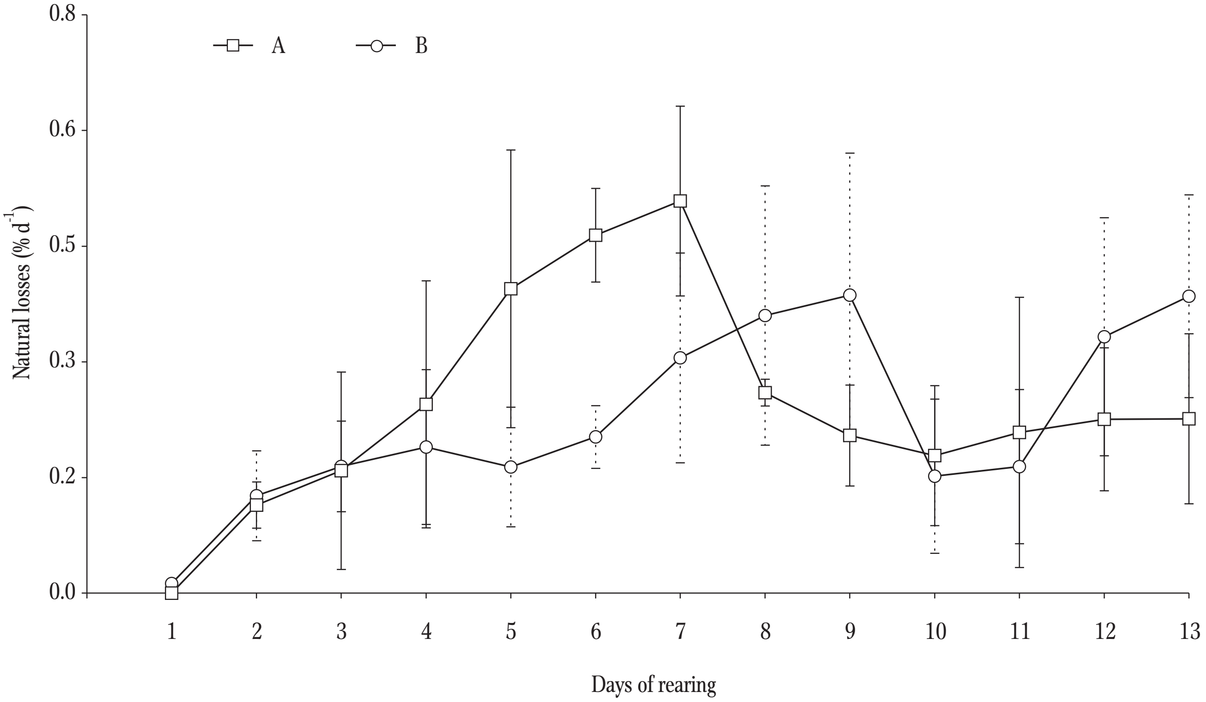

Figure 8. Course of natural losses of juvenile northern pike reared in covered and uncovered tanks (group A – tanks covered by nets; group B – uncovered) (mean values ± SD; N = 3).

between groups SW and N were statistically significant (P < 0.05). Natural fish deaths in the sorted groups were similar to the such losses among unsorted fish and ranged from 0.8 (group N) to 1.1% (group SW; Table 13).

3.9. Experiment IX. Impact of external visual stimuli (covering basins) on the results of rearing juvenile northern pike

Differences were observed in the behavior of the fish reared in tanks that were covered with netting (group A) and not covered (group B). In the first, the northern pike did not react to external stimuli, and reactions such as the sudden movement of the fish generally toward the tank bottom were observed only when feed was being served. In group B, all movements near the tank provoked sudden fish movements. This was particularly apparent directly after the fish were stocked into the tanks. The intensity of these reactions decreased daily, but they were notable throughout the length of the experiment.

Weight gain was higher in the northern pike from group A, and the final body weight was 2.66 g, at a mean daily body weight increase of 11.57% day^{-1} (Table 14). The final body weight in group B was 2.44 g, and the difference among groups was highly significant statistically ($P < 0.01$). The mean daily body weight increase was also statistically lower ($P < 0.05$) in tanks that were not covered at 10.90% day^{-1}. No significant differences were noted, however, in the length growth of the fish in the groups analyzed. Higher survival was attained in group B in comparison to group A (uncovered tanks) at 87.0 and 79.4%, respectively. Lower natural losses were also noted in group B than in group A at 2.4 and 3.9%, respectively, as were losses to cannibalism at 10.6 and 16.7%, respectively. Differences in survival, natural losses, and cannibalism were statistically significant ($P < 0.05$; Table 14). Initially, natural losses in both groups were similar, but from the fourth day of rearing they were distinctly higher in the covered (group A). At the end of the rearing period, higher fish death rates were noted in the uncovered tanks (Fig. 8). The FCR and PER coefficients in both experimental variants were very similar ($P > 0.05$; Table 14).

3.10. Changes in northern pike behavior during early ontogenesis under controlled conditions

D8 (110°D) – Immediately after active swimming began and the fish were stocked into the tanks most of them sank to the bottom in the center of the tanks. About a third of all the fish swam to the water surface in the center of the tanks and positioned themselves facing the oncoming water current. The larvae showed no interest in feed.

D9 (127°D) – Gradually, more fish swam to the water surface. Some of the individuals at the water surface began to ingest feed granules from the water surface or as they fell to the bottom.

D10 (144°D) – Most of the fish stayed in the upper portion of the water column in the center of the tank. On this day, more than half of the individuals had already begun feeding, which was indicated by the characteristic swelling of the body surface. The larvae did not react to movements around the tanks. The first signs of cannibalism were noted. Attacks were staged on individuals located in front of the attacker (type I cannibalism), especially when they moved. These attempts did not end in successful consumption of the victim.

D11 (161°D) – The horizontal distribution of the fish increased, and in this stage of development there were two main fish groups: one in the central part of the tank and another at the water surface along the tank walls. Feed was ingested both from the water surface as well as from the water column as it fell to the bottom. The fish were not observed to gather near the feeders.

D12 (177°D) – Distribution through out the tanks increased, but most of the fish were still located near the water surface at depths to about 15 cm (Photo 1). The efficiency of catching falling granules of feed improved.

D13 (194°D) – The fish were clearly fully distributed throughout the rearing tank. Nearly all individuals exhibited distended bodies, which indicated that the alimentary tracts were full of feed.

D14-D18 (210-278°D) – The larvae were very adept at ingesting commercial feed. It was ingested either directly from the water surface or as it fell through the water column to the bottom of the tanks. Most of the feed was taken from the water surface. When going for falling feed, the larvae usually came at it from underneath. Feed that fell to the tank bottom was not ingested.

D19 (295°D) – Some of the larvae began to stay at the tank bottom and use the unconsumed food gathered there for hiding places. This, in turn, could lead to the occurrence of mold on the gills.

D20 (312°D) – The fish were strongly distributed horizontally, with the greatest concentrations of them in the center and along the walls. Vertical distribution differed with 80-90% of the fish in the surface water layer (to depths of 20 cm). The fish were positively rheotaxic (Photo 2). The northern pike reacted to knocking on tank walls, especially those individuals that were in the immediate vicinity of the stimuli.

D21-D25 (329-402°D) – The feed served by the feeders was ingested immediately after it fell onto the water surface. Sometimes several individuals attempted to consume the same granule. Fish movement aroused interest from other individuals, but this rarely resulted in attacks. Increasing size variation was observed among the fish.

D26-D27 (419-438°D) – Until this moment, the fish did not exhibit any reaction to visual stimuli (movements) in the vicinity of the basins, and they only reacted slightly to manipulations. Fish were observed to feed even during monitoring measurements, after they had been removed from the tanks with sampling nets and placed in a container with water on a scale. Attempts to consume fish caught by the tail were noted. Although these were unsuccessful, the attacked individual sometimes died. Dead fish with partially whitened tails were indications of this phenomenon.

D28-D32 (457-537°D) – Successful attempts to consume caught individuals (type II cannibalism) were observed, and incidences of mutual attack increased. The numbers of dead fish with whitened tails began to dominate.

D33 (556°D) – Fish began to react to movement around the tanks and to hands or nets being placed

Photo 1. Larvae of northern pike in rearing tanks on the fourth day after they began to swim.

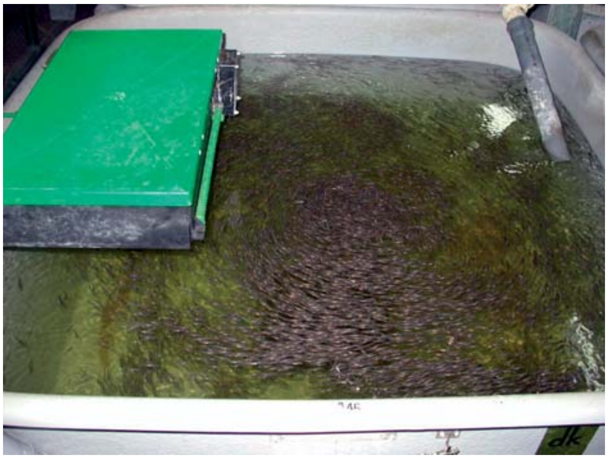

Photo 2. Larvae of northern pike oriented toward the water current (D20).

into the water. This reaction began to occur in more and more fish and it increased in subsequent days.

D34 (576°D) – Because of the increasing differences in fish size and mutual attacks, it was necessary to sort the fish. During this operation, approximately 20% of the largest individuals were separated out. Immediately following the procedure, the fish did not feed, but the resumed normal feeding several hours subsequently.

D35-D39 (595-673°D) – Ten to 15 minutes after the tanks were darkened, the fish quickly moved to the bottom of the tanks where they gathered in one large aggregation. This could have blocked the water flow from the tank. The fish reacted strongly to the water current. When the current was too fast, the fish floated in the tank passively and stopped feeding.

D40 (692°D) – The juvenile northern pike (mean body weight 0.7-1.0 g) reacted very strongly to external stimuli as they demonstrated by sudden flight toward the tank bottom and sides at the moment the stimulus occurred (i.e., when something passed the tank).

D46 (806°D) – The fish gradually grew accustomed to movements around the tanks, and reactions to stimuli were distinctly weaker.

D49 (864°D) – The northern pike attained a body weight of about 2 g. They began to react strongly to manipulations connected to removing them from the tanks. After removal and stocking into tanks, the fish gathered on the bottom of the tanks and attempted to hide in the center of the aggregation (Photo 3). Only after about 12 hours did the fish begin to distribute themselves typically throughout the tanks (as they were before being removed) and begin feeding again.

D52 (920°D) – The first instances of the fish leaping out of the tank were observed. The body weights of the fish that leaped out of the tanks ranged from 2.36 to 3.36 g (body length ranged from 6.6 to 7.6 cm). Increased attempts to leap out of the tanks were associated with manipulations, and they increased substantially after stressful events such as weighing or sorting. In extreme cases, most of the fish can leap out of the tanks. At this moment, it is necessary to cover the tanks or to maintain the water at a very low level. The latter does not allow for appropriate feeding since the feed should be available in the water column for as long as possible. The tank cover should be constructed of appropriately small-sized mesh (approximately 5 mm), because fish that leap forcefully out of the water can become entangled. Most fish try to escape from the tanks at the water inflow. At this age the fish are accustomed to the place in which the feed is served and ingest it as soon as it falls into the water.

Photo 3. Juvenile northern pike gather together while being fished out of the tank (D49).

4. Discussion

Aquaculture is currently developing dynamically. This has provided the impetus for undertaking numerous studies that focus on the possibilities of rearing new fish species that were previously thought to be difficult to cultivate, and many of which were of no interest to either scientists or practitioners. These species include many varieties of predatory fish, of which the northern pike is one. The varied growth rates of predatory fish and associated cannibalism is one of the main problems encountered in the intensive rearing of these species (Loadman et al. 1986, Puvanendran et al. 2008). With the northern pike, it was demonstrated that using reared material to stock open waters significantly improved the effectiveness of such programs (Ziliukiene and Ziliukas 2008). This is why attempts are being made to improve and increase the effectiveness of rearing methods for stocking material of this species. One of the more important biotechnical elements in the production of juvenile stages of northern pike is to determine the optimal environmental conditions for their rearing that permit achieving effective growth and high survival of the fish. Many authors have emphasized that many factors can impact the growth and survival of reared fish (Kestemont et al. 2003).

The fundamental issue that must be dealt with in developing effective rearing techniques for northern pike is cannibalism. That the material used in the rearing of northern pike usually originates from wild spawners only intensifies this problem since wild fish are more prone to aggressive behavior than are domesticated fish (Hedenskog et al. 2002). Cannibalism presents in two forms: types I and II (Baras et al. 2000). In the first type, the victim is caught but only partially eaten, and the portion of the victim that cannot be consumed is rejected. This can occur at even small size differences and has been noted among African catfish, *Clarias gariepinus* (Burchell), (Adamek 2003) and Acipenseridae fish (Szczepkowski, unpublished materials). In type II cannibalism, the victim is consumed whole by the cannibal, and this requires adequate size differences between the fish. In northern pike, type I cannibalism occurs almost exclusively among larval stages and is manifested primarily in the cannibal attacking the tail of its victim. This usually occurs when the victim moves its tail. This type of cannibalism does not usually cause greater numbers of deaths. Type II cannibalism is the prevalent one among northern pike since this fish is highly capable of consuming victims thanks to the particular structure of it jaw joint (Janec-Susłowska 1957, cited in Załachowski 2000). It is uncommon for the captured victim not to be consumed. This is advantageous in controlled rearing as losses are confined to the individuals that are actually consumed. When aggression levels rise in other fish species and mutual attacks increase, often the numbers of injured (bitten) individuals that die quickly also increase. As a result, so-called natural deaths rise. This is noted during the controlled rearing of larval perch, *Perca fluviatilis* L., pikeperch, *Sander lucioperca* (L.), and walleye, *Sander vitreus* (Mitchill) (Loadman et al. 1986, Baras et al. 2003, Szczepkowski, unpublished data). Most authors reporting on the rearing of northern pike confirm that intense cannibalism is a problem (Kucska et al. 2006, Ziliukiene and Ziliukas 2006). Giles et al. (1986) emphasized that losses to cannibalism during larval northern pike rearing comprised from about 54 to 96% of the overall losses. Similar results were obtained in the current study of older northern pike stages. In nearly all the experiments most of the losses were due to cannibalism, and sometimes accounted for as much as 93% of total losses (experiment VII, III stage, group O). This figure could have even been higher since some of the natural deaths were actually caused by unsuccessful attacks and injuries that led to death.

The cannibalism phenomenon is widely observed among northern pike in the natural environment and in pond rearing (Bry et al. 1992). Many authors, however, emphasize the regulatory character of this phenomenon that prevents excessive population growth of this species (Persson et al. 2006). This is supported by the highly territorial nature of the northern pike. Individuals occupy separate areas (Nilsson 2006), and this species only forms larger aggregations during spawning. Reportedly, in Bavaria it is estimated that 100 m of riverine waters are inhabited by on to five northern pike individuals (Leuner and Klein 2000). Additionally, the northern pike anatomy permits it to catch and consume relatively large prey (Nilsson and Brönmark 2000), which also promotes its predatory life strategy. The body length of the consumed victims can comprise 70-80%, and even 90.9% of the length of the cannibal northern pike (Hunt and Carbine 1951, Ziliukiene and Ziliukas 2008). During the experiments described in the current work, fish even attempted to prey on victims of the same or larger sizes. Such cannibals usually failed and prey was released after several unsuccessful attempts to consume it.

Attempts and studies of the possibilities of rearing northern pike under controlled conditions have, to date, been limited to short-term larvae rearing. These have indicated that numerous factors can influence, above all else, larval growth and survival (Engström-Öst et al. 2005). The current data presented indicated that in case of juvenile stages of northern pike there is a range of biotic and abiotic factors that can have varying degrees of influence on growth rate, survival, and the feed conversion ratio.

One of the most important environmental factors that influences the metabolism and life transitions of many fish species is water temperature (Kelly and Arnold 1999, Cotton et al. 2003). The results of the current studies indicate that of the analyzed temperature range of 20-28°C, the optimal temperature for juvenile northern pike growth is 28°C. The fish held at this temperature attained the highest weight gain rates at very high survival rates. Thus, the optimal temperature for rearing juvenile northern pike is higher than that determined for the larvae of this species. According to Wolnicki and Górny (1997) the optimal temperature for the larval stage is 24°C, while Hokanson et al. (1973) noted the fastest larval growth at 26°C, but this was accompanied by increasing mortality. Similarly, Górny (1992) reported that increasing cannibalism is noted at higher rearing temperatures. Metabolic tests of older northern pike (with body weights exceeding 50 g) indicated that oxygen consumption and ammonia excretion increase at temperatures from 20 to 24°C, but that these are not great (Zakęś et al. 2007). The optimal temperature for northern pike growth might even be higher than 28°C since the growth rate in the current study did not slow, which is something that occurs when the physiological optimum is exceeded (Kamler 1992, Wolnicki 2005). The current studies indicate that northern pike is highly "plastic" with regard to water temperature. This opinion was formulated primarily with regard to embryos and larvae of this species (Załachowski 1973, Ziliukiene and Ziliukas 2002). Northern pike larvae tolerate short-term increases in temperature up to 34°C; however, with these developmental stages this can be recognized as a trait that allows them to adapt to the significant fluctuations in temperature in the shallow littoral zone waters that are their natural habitat in the early stages of individual development (Lindroth 1946, cited in Załachowski 1973). The optimal temperature for rearing juvenile northern pike as determined in the current study is higher than that which occurs in the natural environment. Similar observations have been reported with regard to a variety of other fish species, for which optimal temperature for growth and the tolerable temperature range are both much higher than those encountered in the natural environments. An example of this are fish from the Acipenseridae family, especially Siberian sturgeon, *Acipenser baerii stenorrhynchus* (Nikolski), for which the optimal temperature for growth is about 24°C, and tolerated temperatures are as high as 30-32°C (Kolman 1999), whereas in the natural environment of this species the water temperature rarely exceeds 17°C (Ruban 1999).

It has been confirmed that temperature has an impact on the survival of predatory fish. Increases of temperature from 22 to 24°C caused substantial decreases in survival among juvenile pikeperch reared in ponds on commercial feed (Zakęś 1999b). The high survival of northern pike at the temperature of 28°C in the current study could have resulted from its quick return to feeding following manipulations (stocking the fish into tanks). The low level of cannibalism in this group might be confirmation of this. Faster weight gain at the highest temperature tested also contributed to decreased losses since increased weight lowers cannibalism significantly.

The impact of temperature can also be modified by other factors, such as the annual cycle. Chipps et al. (2000) confirmed that some metabolic indices (such as oxygen consumption) noted for muskellunge, *Esox masquinongy* Mitchill, held at the same temperatures under laboratory were significantly higher in summer and fall than in winter. Photoperiod can also influence the optimum temperature (Talbot 1993); however, with northern pike this factor appeared to be less important. Water temperature can also influence the sensitivity of the fish to other factors; for example, it has been confirmed that as temperature increases, northern pike individuals become more sensitive to increases in salinity (Jacobsen et al. 2007).

Values of the feed conversion ratio (FCR) for the northern pike in the current study increased as the temperature increased. This could have been caused by the higher feed ration served, or by the poorer utilization of feed because of the worsening oxygen conditions resulting from the lower oxygen solubility at higher temperatures.

Rearing northern pike at high temperatures (28°C) presents another problem when using this as stocking material. Such temperatures are practically non-existent in the natural habitat of the northern pike. In the 2001-2005 period, the maximum water temperature at ponds of the Dgał EH, where the current experiments were conducted, did not exceed 26.7°C (Szczepkowski, unpublished data). The challenge is to acclimate the fish to new thermal conditions (Górny and Wolnicki 1993), which is doubtless more difficult to accomplish than it is when rearing is conducted at lower temperatures. Simultaneously, materials reared at high temperatures have substantially higher energy reserves (as is indicated by the statistically higher condition coefficient). Thanks to this, the period during which the fish will be able to acclimate to the new, different environmental conditions might extend in time. This hypothesis requires further investigation.

Light intensity in combination with other rearing factors is rarely the subject of studies of fish rearing biotechniques. It has long been recognized that light (photoperiod) plays an important role in fish maturation and reproduction processes (Bieniarz and Epler 1991). Studies have confirmed significant differences in the influence of light on the growth and survival of many species, and differences within the same species that inhabit different regions, such as cod, *Gadus morhua* L. (van der Meeren and Jůrstad 2001). It was confirmed that light intensity (from 0.7 to 70 lx) influences the frequency of feed consumption and the period of the most intense feeding in rainbow trout, *Oncorhynchus mykiss* (Walbaum) (Mizusawa et al. 2007). Although lighting within a range of 200 to 2000 lx did not influence the growth of larval *Solea senegalensis* Kaup, it did have an impact on survival during the metamorphosis stage. The highest values of the survival index were obtained at a light intensity of 1000 lx (Cañavate et al. 2007). Other studies indicated that larval cod growth and survival increased with increasing light intensity from 300 to 2400 lx; this stemmed from the more effective uptake of feed (Puvanendran 2002). Some species prefer a low light level. For example, pikeperch aged 0+ and 1+ preferred staying in the darkest areas at light intensities of 1 to 50 lx and 25 to 300 lx (Luchiari et al. 2006). Maintaining permanent darkness is also recommended for African catfish, *Heterobranchus longifilis* Val. (Baras et al. 1998).

Zigler and Dewey (1995) confirmed that larval and juvenile stages of northern pike are phototaxic positive at the age of 6 weeks, something that has been exploited by using lit traps to catch them. Pyka (1993) noted a relationship between the intensity of feeding and increasing light in ponds, while according to Dobler (1977), northern pike exhibit the greatest predatory activity at low light below 1 lx. In the current study, the light intensity investigated was not found to have had an influence on northern pike growth or survival, which is an indication that this species is highly tolerant of fluctuations in this factor. This is confirmed by the fact that even at a very high light intensity (up to 60 000 lx) and great fluctuations over the course of the day, larval and juvenile northern pike consumed commercial feed very effectively (Chybowski and Szczepkowski, unpublished data). Similar observations were recorded in walleye fed zooplankton; their stomachs contained similar numbers of prey items consumed in the day and at night (Applegate 1981). In other studies (Szczepkowski, unpublished data), northern pike were observed to not feed at all when kept in total darkness (light intensity 0 lx). In combination with these results, the current studies indicate that the minimum lighting level at which juvenile northern pike can feed on commercial feed is between 0 and 1.1 lx.

In addition to light intensity, photoperiod might be significant (Nwosu and Holzlöhner 2000). Preferences regarding photoperiod can differ among the different developmental stages of a single species (Purchase et al. 2000). In experiment II, 24-hour lighting was applied as is recommended for rearing northern pike (Wolnicki and Kamiński 1998). Using a 24-hour lighting period was also prompted by the lack of northern pike feeding in the darkness.

In addition to lighting, the color of the inside walls of rearing tanks can influence the results of rearing. Both of these factors can affect fish behavior, as well as the visibility of feed and the ease or difficulty the fish have in obtaining it (Petrell 2001). There have not been any studies to date on the effect rearing tank wall color has on northern pike. The current experiments were conducted in tanks with green walls since this color has been proved appropriate for other species of fish (Bransden 2005, Luchiari and Pirhonen 2008).

There is currently no precise data available regarding the optimal feeding ration for juvenile northern pike reared under controlled conditions. This is significant since predatory fish, of which northern pike is one, require a high feed ration to minimize fish aggression during rearing. The impact of the daily feed ration on rearing results has been confirmed in many fish species (i.e., Hung and Lutes 1987, Fiogbé and Kestemont 2003, Rónyai and Csengeri 2008). In general, a higher feed ration will have a positive impact on fish growth, but there are limits. The quantity above which the feed is no longer consumed is the so-called maximum ration (Cotton and Walker 2005). Restrictive feed rations decrease the growth rates and contribute to greater variation and competition within groups (Zakęś et al. 2003), which can lead to a greater incidence of mutual injury (Andrew et al. 2004). In African catfish the survival rate was significantly higher at a daily feed ration of 6-10% of body weight in comparison to rations of 2-4% (Al-Hafedh and Ali 2004). However, while shifting the feed ration for pikeperch with a range of 2 to 6% did not influence the survival of the fish, it did impact the growth rate and the effectiveness of feed utilization (Bódis and Bercsényi 2009).

Automatic feeders, which were used during the rearing of juvenile northern pike, carry the risk of overfeeding the fish (Paspatis 1999), which, in turn, risks causing deteriorating environmental conditions. This can occur because of decreasing water quality as a result of increasing concentrations of harmful elements, mainly nitrogen, that come from decomposing feed and fish metabolic products, the rate of which is linked strictly with feed ration (Thomas and Piedrahita 1998, Zakęś 1999a). This places a greater burden on the water purification devices of recirculating systems and increases the amount of stress the fish are subjected to (Chang et al. 2005).

Results of previously published studies suggest that the initial feed ration for northern pike should be as high as 70% of the fish biomass (Wolnicki and Kamiński 1998). The optimal ration for juvenile northern pike during the period studied was 8% of the fish biomass d^{-1} between days 72 and 80 of life and then 6% in later periods. It is possible that a lower ration (4 or 6%), at which the fish could have achieved comparable growth, might have been more advantageous in the early period (between D72 and D80). However, the groups fed this ration size exhibited much higher losses to cannibalism, which maybe occurred precisely at this time. Throughout the entirety of rearing, the size of the feed ration did not significantly influence either fish growth or intra-group differences. This might confirm that the lower survival noted in groups fed smaller feed rations was caused by increased cannibalism in the initial adaptation period. Increased feed rations ranging from 1 to 2% of fish biomass result in increased weight gain of northern pike (body weight of 8 g) with a simultaneous decrease in the feed conversion ratio (Kucska 2007). In these studies, the author did not, however, observe any cannibalism, which is linked to the size of the fish since this phenomenon at this time is substantially limited.

It should also be borne in mind that when using higher feed rations a portion of the feed will go unconsumed and will fall to the bottom. Because larval and juvenile northern pike do not move much, they are relatively susceptible to gill infections and consequently, death, when large quantities of unconsumed food are on the tank bottoms (Wolnicki and Kamiński 1998). This is even more dangerous in that juvenile pike tend to seek out hiding places, and which are readily available among the unconsumed feed on the bottom. This is why it is necessary to clear away unconsumed feed systematically, which makes rearing more labor intensive. Reducing the quantity of unconsumed can also be achieved by stocking northern pike rearing tanks with bottom-feeding species such as sturgeon (Szczepkowski and Szczepkowska 2006). However, it is not always possible to apply this solution.

Choosing the appropriate feed is one of the basic elements of rearing fish, and considerations in this include its properties (mainly the composition of the contents of protein and lipids), color, and granule size (among others, see Glencross 2006, Grisdale-Helland et al. 2008, Mohanta et al. 2008). The type of feed used depends on the species and size of the fish being reared (Kolman et al. 2008), and even the purpose for which they will serve. One type of feed is used in fish for consumption, while another type of feed is used for fish that will be used for further reproduction. In the case of juvenile stages, it is crucial that the fish accept the feed served quickly since they have relatively low energy reserves in comparison to adult fish, and they cannot survive longer periods of starvation. The metabolic rate of juvenile fish is also much faster (Kamler 1992). The acceptance and effective consumption of feed are largely conditioned by the fish being able to see it, which, in turn, is determined by a variety of factors, such as lighting. Petrell (2001) noted that fish fed in the morning hours at low light levels consumed much less feed when the granules were of a silver rather than a brown color. Other factors that influence acceptance of feed by the fish is its size. A larger feed granule size increases the possibility of the fish seeing it. However, larger granules sink faster, which reduces the time of feed availability on the surface or in the water column. In rainbow trout it was confirmed that decreasing the availability period of feed depending on the height of setup over the water of the automatic feeder wings can limit fish growth (Noble et al. 2007). It was also noted that the size of the feed granules influences the rate of its evacuation. In African catfish fed feed of various granule sizes, the evacuation rate of feed decreased as the granule size increased (Hossain et al. 2000). These authors also confirmed that the granule size influenced the growth rate of the fish. The most appropriate feed size for fish with a body weight of about 1g was between 1.5 and 2.0 mm.

The results of the current studies indicated that changes in feed granulation size within a narrow range (one degree of granulation) does not have a significant impact on its consumption by juvenile northern pike or on the rearing results achieved, which appears to indicate that this species is highly flexible with regard to the size of feed it consumes (Craig 2008). These results also indicate that unlike larvae, juvenile northern pike do not prefer the largest feed available (Wolnicki and Kamiński 1998). It should also be borne in mind that although juvenile northern pike begin to feed on fish fairly quickly, during the first phase of feeding they prefer zooplankton and consume as many as several hundred of them daily (Ziliukiene and Ziliukas 2002). Thus, in this regard the feeding of juvenile pike in controlled rearing is very similar to the feeding of juvenile stages in the natural environment. Natural behavior and the feeding habits of fish can sometimes disrupt controlled rearing. For example, in *Sparus aurata* L. it was observed that the hardness of commercial feed, which differs from the natural feed, makes its consumption difficult (Andrew et al. 2003). This phenomenon was not noted during the current studies, and instances of juvenile pike spitting out feed were very rare.

The next significant factor in appropriate fish feeding, in addition to feed ration, is its serving in daily cycles. The results obtained by various researchers are ambiguous concerning the optimal frequency and length of fish feeding within the daily cycle, and also indicate that different species exhibit different preferences. For example, twice daily feedings are sufficient to produce optimal growth in *Paralichthys olivaceus* (Temminck and Schlegel) (Kim et al. 2007), while serving feed to *S. aurata* three times daily was too infrequent and resulted in decreased fish growth (Velazquez et al. 2006). The length of the feeding period per day is accompanied by a host of other issues, such as changes in lighting cycles that can cause changes in active feeding, depending on preferences, and impact the results of rearing. It was confirmed in Japanese meagre, *Argyrosomus japonicus* (Temminck and Schlegel), that at the same feed serving periods results were dependent on the photoperiod applied. A lighting cycle of 12L:12D caused lowered survival, while a 24L:0D lighting regime lowered growth rates (Ballagh et al. 2008). The optimal daily feeding period should take into consideration the developmental stage of the fish. Younger fish usually require feeding for longer periods and more frequently than do older individuals (Robinson et al. 2001).

Studies of the common whitefish, *Coregonus lavaretus* (L.), indicated that the growth rates of the fish fed the same feed ration but at various times in a daily cycle (from 6 to 24 h) differed in the initial period, but after a certain time the fish that were fed for a shorter period developed a mechanism that allowed them to attain similar growth to the group fed for longer periods (Koskela et al. 1997). A similar mechanism was noted in yellowtail flounder, *Limanda ferruginea* (Storer), where it was confirmed that the fish fed less frequently consumed more feed granules during a single feeding and were more active (2002). In other fish species, for example barramundi, *Lates calcarifer* (Bloch), the growth rate of fish fed for 24-hour cycles did not differ in relation to fish fed only during the day or the night (Harpaz et al. 2005). This was the case with rainbow trout that were fed for either 12 or 24 hours per day (Shima et al. 2001). However, in the last case, it was noted that shortening the feeding period caused increased cannibalism. In order to avoid cannibalism in northern pike, it is recommended to feed the fish 24 per day (Wolnicki and Kamiński 1998). This concurs with results obtained in the current studies with smaller experimental material (with a mean body weight of 0.2 g), in which the highest survival was also obtained when the fish were fed 24 hours per day. However, in older fish the best results were noted with a 12 hour feeding period. In their studies of juvenile northern pike with an initial body weight of 9.6 g, Kucska et al. (2007) confirmed faster growth and higher survival in fish fed all day in comparison to those fed twice a day. It would appear, however, that serving feed only twice a day might be too short a period. Additionally, in the study cited floating feed was used, which could also have had an impact on the manner and effectiveness of its consumption.

It is difficult to determine unambiguously the cause of differences in the results obtained in studies of younger and older fish. It appears, however, that they could have been related to the significant changes in fish behavior that occur in this period, during which juvenile northern pike are already very sensitive to changes and external stimuli. For the fish that were fed around the clock, feed was loaded in to the automatic band feeders twice a day. This could have caused the fish additional stress and lengthened the period during which they did not feed. Additionally, towards the end of the serving period, more feed is served by the band feeders, which could have resulted in some of the feed not being consumed and falling to the bottom. In effect, with twice daily servings of feed the quantity of unconsumed feed will be larger, while the actual "available" feed of 24 hour feeding is smaller. This might be significant, as experiment III indicated feed ration is a factor that has a strong influence on the results of rearing. This situation can be remedied by using feeding systems in which the feed is released by hungry fish themselves, which would best meet their feeding needs (Paspatis 2000, Valente 2001). However, such a system is not possible to deploy with juvenile northern pike, because of the small size of fish and the low level of movement they exhibit.

It should also be considered whether the better rearing results of older fish using shorter feeding periods are not an effect of their natural behavior. It is possible that reared northern pike liken their feeding behavior to the feeding rhythms of wild fish, which do not consume food continuously, but rather in portions resulting from successful hunting. This might indicate that keeping juvenile northern pike in readiness to consume feed throughout the day is not advantageous. This phenomenon intensifies as the fish grow older, and although they are trained to feed, they do so proportionally less frequently and very irregularly. This is one of the main reasons that the rearing of older fish (body weight in excess of 15-30 g) is not effective even though there is practically no cannibalism.

Although indicators of growth and survival are important for determining the appropriate feeding regime, the impact feeding and fish metabolism have on the environment of closed recirculating systems must also be considered. It is known that the manner in which the feed ration is divided causes daily fluctuations in oxygen consumption and ammonia excretion (Zakęś 1999a). Feeding periods that are too short increase the possibility of critical amounts of ammonia occurring.

Abundance is considered to be a significant factor that influences growth and survival of larval and juvenile stages of northern pike under natural conditions. Bry (1980) maintained that a substantial decline in survival occurred when the stocking density of three-month northern pike was increased from 7 to 33 individuals 100 m^{-2}. Increased stocking density also means increasing the number of potential victims that can be lost to cannibalism. Increasing the number of fish (victims) does not always mean that predators catch them more easily. During studies conducted under controlled conditions, it was confirmed that increasing numbers of victims had an impact on the success of perch attacks, but not in those of pikeperch or pike (Turesson and Brönmark 2004). The authors explained this by the varied hunting methods employed by these species, group methods for perch and individual methods for pikeperch and pike. Grimm (1981) made similar observations of northern pike in ponds, and he maintained that the final fry biomass was not limited by the abundance of fish-victims. Similar conclusions can be drawn from the results of the current study. Increased stocking density during rearing did not cause increased losses; to the contrary, the lowest survival was obtained at the lowest stocking density. Thus, it can be accepted that in the initial and final stocking density range studied (1-5 kg m^{-3} to 2.9-13.4 kg m^{-3}), increases in the value of this factor did not cause negative results. Different results were obtained by Ning-Yu et al. (2006), and they concluded that there was a high correlation between the growth rate of juvenile northern pike and stocking density. However, in this case larger fish were fed natural feed at low initial northern pike stocking densities (from 8 to 40 individuals per m^{-3}, which is from 0.16 to 0.8 kg m^{-3} – current author's calculations). Similar results to those of the current study were obtained in rearing studies of juvenile pikeperch by Szkudlarek and Zakęś (2002). The magnitude of cannibalism was similar at initial stocking densities of 0.99 to 2.31 kg m^{-3}. These authors also confirmed that there was a strong correlation between stocking density and cannibalism in younger developmental stages of pikeperch reared on feed in recirculating systems (Szkudlarek and Zakęś 2007), which is why it is possible to assume that the optimal stocking density ought to be determined for the various developmental stages of the reared species. Increased stocking density can have a significant impact on increased incidences of aggressive behavior in migratory sea trout, *Salmo trutta* L. (Hedenskog et al. 2002) as well as on symptoms of stress (Caipang et al. 2008). This might be partially because the differences between the sizes of the largest and smallest individuals increase at high stocking density (a larger number of groups), which is conducive cannibalism (Folkvord 1997).

On the other hand, it is known that many fish species, especially those that are cultivated, exhibit better growth when group size is larger than at lower stocking density (Potthoff and Christman 2006). Some authors link this to greater competition for feed and heightened appetite (Honer et al. 1987, cited in Potthoff and Christman 2006). Similar phenomena are observed in fish that shoal. For example, perch that are held in isolation exhibit weaker growth even though they consume more feed than individuals held in groups, which the authors attributed to the effects of stress (Strand et al. 2007).

In consideration of the economic aspects of rearing juvenile northern pike, the optimal initial stocking density is the highest one applied in the current study, which was 5 kg m^{-3}. It is also likely that the stocking density studied was not large enough to trigger a sharp increase in cannibalism, which has been noted in intense rearing of other fish species, such as Nile tilapia, *Oreochromis niloticus* (L.) (Fessehaye et al. 2006).

The choice of the appropriate rearing tank is significant for the effective rearing of various fish species (Rasmussen et al. 2005), and optimal solutions should take into consideration natural behavior. Numerous studies indicate that the color of the rearing tanks influences the effectiveness of rearing, in, among other species, juvenile white seabream, *Diplodus sargus* (L.) (Karakatsouli et al. 2007), larval spotted sand bass, *Paralabrax maculatofasciatus* (Steindachner) (Pena et al. 2005), and haddock, *Melanogrammus aeglefinus* (L.) (Downing and Litvak 1999). Observations of the rearing of other predatory fish species also indicate these fish exhibited preferences with regard to rearing tank parameters (Zakęś 1997, Adamek 2003). A significant element of the suitability of various tanks was shape. Two basic types of tanks are generally used – round (rotational) and rectangular (ranging in shape from square to long troughs; Labatut and Olivares 2004). The shape of the tank can influence water flow and the movement of feed, the movement of fish, and, through these, to changes in the oxygen content in the water column (Reig et al. 2007). Trough-shaped tanks are not suitable for northern pike rearing (Wolnicki and Kamiński 1998). The comparison of the effects of rearing northern pike in square and round tanks indicates that the former is more suitable. In all of the stages studies in both tank shapes the growth rates were comparable, but the survival in the square tanks was much higher. The differences in this parameter in older material (stage III of the studies) are of particular interest. Losses among fish of this size are usually only slight, while in the round tanks they were nearly 15% and were due almost exclusively to cannibalism. It is likely that this was due to the varied behavior of the fish in the two tank types. The greater distribution of the fish observed in the round tanks was conducive to cannibalism, as was observed previously in other studies (Szczepkowska and Szczepkowski 2004). The fish cannibals attempted to occupy separate spots that allowed them to attack their victims. Similar conclusions were reached by Mélard et al. (1996a), who confirmed that in order for cannibalistic tendencies to arise, there has to be an appropriate minimal area of available territory. It is not, however, fully understood what led the northern pike to disperse in the round tanks; it is possible that the cause was the equally distributed water current or the lesser water depth than in the square tanks.

Sorting fish during rearing is a common procedure for many different species: it can lead to improved growth; it can simplify rearing after sorting when it is possible to use one type of feed; and it is also used to prepare fish for sale (Jensen 1990). Not sorting fish can lead to large losses caused by injury inflicted on fish by others and by fish consuming other fish, while the procedure itself is an additional source of stress (Portz et al. 2006). For so-called species sorting, computer techniques are currently employed that allow nearly 100% accuracy in separating even several species of fish (White et al. 2006, Zion et al. 2007). Dividing fish into size groups is substantially more difficult, but it is commonly applied in rearing in fish hatcheries. The aim of it is to reduce cannibalism, make feeding easier, and increase the growth of smaller fish (Saoud et al. 2005). Additionally, fish of various sizes can exhibit different behaviors. For example, as early as at the first exogenous feeding, great differences are noted in the behavior of larger larvae (hatched from larger eggs) of Arctic charr, *Salvelinus alpinus* (L.), in relation to smaller individuals. Larger individuals swim more actively and take feed from the water surface, whereas smaller individuals spend significantly more time near the bottom of the tanks (Benhaïm et al. 2003).

The results of sorting various species of fish are ambiguous. After sorting African catfish according to size, Martins et al. (2006) noted that the degree of aggression measured as the number of fish with injuries in all of the studied groups was still high, but it was the lowest in the largest group of sorted fish. These authors also reported that, throughout the duration of the experiment, the number of bitten individuals decreased in the two groups of larger sorted fish in comparison to the number of such individuals in the unsorted and the smallest sorted fish groups. Among *Centropomus parallelus* Poey, it was demonstrated that both cannibalism and natural losses were lower in the homogenous group than in the heterogenous one (Corrêa and Cerqueira 2007). In yellow perch, *Perca flavescens* (Mitchill), sorting was not noted to have had an impact on the final biomass or survival of the fish held in ponds. Positive effects were achieved in the group of the largest sorted fish in that the share of fish of commercial size increased, which shortened rearing time (Wallat et al. 2005). Sorting juvenile turbot, *Scophthalmus maximus* (L.), and pikeperch did not improve the effectiveness of rearing (Sunde et al. 1998, Zakęś et al. 2004), and greater growth was achieved in perch that were unsorted (Mélard et al. 1996b).

The results of the current experiment indicated that sorting had a positive impact on the survival of juvenile northern pike. Cannibalism was highest among fish that were not sorted, and despite this the final variation coefficient (V) of this group was the lowest. This indicates that in this group the fish that were eaten most frequently were the smallest ones. Confirmation of this is seen in the fact that the fish in this group achieved the highest final body weight. They achieved growth that even exceeded that noted in the group of larger sorted fish. Similar observations were made during the rearing of *C. parallelus*, where better growth was also observed among unsorted fish, which was also linked to the selective consumption of smaller individuals (Corrêa and Cerqueira 2007).

Sometimes sorting can have a negative impact on fish growth. For example, the daily growth of cod in sorted groups was lower than that in unsorted groups (Lambert 2001). The variable results obtained by various authors regarding the effects of sorting could also have been caused by the biological characteristics of the species studied and by the sizes of the fish subjected to this procedure. Considerable levels of cannibalism were noted in cod with mean body weights of 0.6 g, while it did not occur among cod that weighed 10 g (Folkvord and Otterå 1993). Thus, it is likely that the positive impact of sorting on survival can be anticipated when the procedure is conducted during the period when cannibalism is at its peak, which was the case with regard to the current studies.

Confirmation of the hypothesis regarding the necessity of sorting the juvenile northern pike at intervals of about two weeks is seen in the curve of natural deaths in experiment VI (with different initial stocking densities). After a gradual decrease in fish deaths during rearing, they increased toward the end of the experiment. It appears that this was the result of type I cannibalism. Initial attempts by the fish to attack were rare and usually unsuccessful; however, as size differences within groups increased, so, too, did the number of successful cannibalistic attacks. This is why not sorting the fish leads to a rapid increase in cannibalism, a lack of interest in feed, and drastic losses.

There is little information in the literature regarding the impact of external stimuli from the vicinity of rearing tanks on fish behavior and the results of their rearing (Davidson et al. 2009). This also refers to the effects of using rearing tank covers. Various types of tank covers are used during the rearing of many fish species in order to prevent them from escaping (Mohler 2003, Race and West 2007). They are also indispensable during northern pike rearing. In conditions that are close to natural ones (artificial streams) it was demonstrated that after installing wooden structures in open areas the abundance of Japanese dace, *Tribolodon hakonensis* (Günther) increased (Fujimoto and Iwata 2005). In this instance, this was linked to the fish exploiting the covered areas to hide from predators.

In the current experiment, the tanks were covered in order to reduce the impact on fish behavior of activities and manipulations conducted in relation to rearing. This was implemented before the fish began to leap out of the tanks and during the period when the northern pike begin to react very strongly to external stimuli, which permitted evaluating the changes that occurred during this time. It was assumed that isolating fish from external stimuli would produce positive final results. The effect of covering the tanks, however, was quite the opposite. The fish did achieve better growth (greater daily growth and better final body weight), but survival in these groups was substantially lower, generally due to higher rates of cannibalism. The cause of this must be sought, among other reasons, in the different behavior of the fish. In the uncovered tanks the fish reacted by moving (escaping) around the tank, while no reactions were noted in the covered tanks. In the latter case, the lack of disturbing stimuli from the outside could have permitted the fish to assume convenient spots for attacking other individuals. This can be confirmed by other studies in which it was noted that individuals prone to cannibalism (evaluated based on considerably larger sizes) attempted to occupy spots that were not willingly chosen by the majority of fish (Szczepkowski and Szczepkowska 2006). These places were mainly near the bottom of the tanks, while most of the fish stayed in the upper water layer. During joint rearing of northern pike and sturgeon, the presence of the latter reduced the degree of cannibalism. This might have resulted from the sturgeon occupying the bottom zone and limiting the access of the northern pike cannibals to this zone, thus, also limiting their hunting (Szczepkowski and Szczepkowska 2006).

The results of rearing at different stocking densities and in rotation tanks (experiments VI and VII) indicate that there are no distinct negative effects with growing stocks. Simultaneously, the increased threat of cannibalism when the fish have relatively more space and there is greater distribution (Szczepkowska and Szczepkowski 2004) confirms the hypothesis that the lack of stress factors and adequate space encourages aggressive behavior in juvenile northern pike. From the point of view of rearing under controlled conditions, an advantageous factor might be to maintain water transparency at an adequate level as this might have a positive effect on the intra-group behavior of northern pike. Nilsson et al. (2009) observed among northern pike held in groups that as the water became turbid mutual negative factors appeared that resulted in lower feed consumption. Water turbidity, however, is of varied significance for different species, and much better rearing results are obtained in walleye when they are reared in turbid water (Bristow and Summerfelt 1994).

The impact of some factors might become apparent in varied ways in fish of different ages, especially if they are related to behavior. An example of this is the different behavior of juvenile northern pike in covered tanks. In the current studies, the reared fish already began to react strongly to external stimuli at the age of 27 days. It is possible that in younger fish that reacted very strongly to external stimuli the effects of covering the tanks were not apparent or significantly lower.

The results of the current studies indicate that the factors that most influenced the results of rearing northern pike juveniles were water temperature, tank type, stock sorting, and the size of the daily feed ration. The length of time the fish were fed and covering tanks had lesser effects on the finals results of rearing. These factors can influence growth, survival, and the feed conversion ratio (temperature and covering the tanks), while other factors can cause changes in survival and the feed conversion ratio, but they do not determine the growth rate of the fish (sorting, applying varied feed rations). It must be borne in mind in this case, that some of the biomass growth of the stocks with lower survival rates (and at the same time higher cannibalism rates) was the result of intensifying cannibalism. In effect, advantageous FCR parameters were obtained even in the groups in which there was pronounced cannibalism. For example, in experiment III a better FCR coefficient value was recorded in the groups fed the lowest feed rations, even though there were higher losses to cannibalism. Changes occurring in fish during ontogeny development, primarily in behavior, influenced the impact of particular environmental factors. One clear example is the variable preferences concerning the length of the feeding period. These changes increase as the fish grow, which means that intensive rearing of northern pike with a body weight exceeding 30 g is not very effective, while older stocking material faces substantial difficulties in adapting to natural conditions and feeding on fish (Szczepkowski and Szczepkowska 2004). Basic problems with rearing older stages of juvenile pike include their weak consumption of commercial feed and relentless attempts to leap out of the tanks (Szczepkowski, unpublished data). Since weak feed consumption occurs in fish that had previously had no problems consuming it and were accustomed to it, these changes are likely the result of factors other than feeding. In combination with observations of fish behavior during rearing, it is plausible that as the fish grow they become more sensitive to changes occurring in their surroundings. Indications of this include the initial, short-term descent of the fish toward the rearing tank bottoms and limiting feeding after the occurrence of stimuli, followed by attempts to leap out of the tanks. This type of reaction was first noted in fish following 560°D and at a body weight of about 150 mg, and as the fish continued to grow these reactions intensified. An example of this might be the changes in the effectiveness of feed utilization during experiment III. Immediately after the fish were stocked into the tanks the feed conversion ratio was very high, which resulted from weak feed consumption in reaction to stress. In subsequent periods, the FCR value in all the groups decreased distinctly. After attaining a body weight exceeding 5 g, changes in the behavior of the fish were so pronounced that they require adjustment in rearing techniques. These include limiting manipulations related to rearing (tank cleaning, weighing, feeding) to the absolute minimum while simultaneously ensuring that the fish cannot leap out of the tanks.

In addition to providing optimal biotic and abiotic conditions, other methods for improving rearing results are currently being sought, including, among other ways, through the application of feed with the appropriate composition. For example, studies confirm supplementing feed with the appropriate amino acids can influence the levels of aggression and associated cannibalism. Studies by Höglund et al. (2005) indicated that the addition of tryptophan to diets lowered the incidence of aggressive behavior significantly in juvenile cod. Hormones were also applied to solve this problem (Hey et al. 1996).

Providing appropriate, optimal environmental conditions for the rearing of a given species is key. The results of the current studies on rearing juvenile northern pike indicate which factors have the greatest impact on the rearing results and what the optimal values of these parameters are. Using this knowledge to develop biotechniques for rearing northern pike stocking material under controlled conditions allows choosing the moment when open waters are to be stocked. This is very important for the survival of this material in the natural environment. Releasing the fish too soon can mean that there is a lack of food in the environment, while releasing the material too late puts it under too much pressure from predators, including northern pike (Grønkjær et al. 2004). Rearing larval and juvenile stages under highly controlled conditions presents many threats to the fish, which will ultimately be released into the natural environment. Food is in constant and relatively easy supply, the environmental conditions are maintained at optimal levels, and there are no threats from natural predators. Additionally, the rearing conditions can shape fish behavior (Lee and Berejikian 2008), which can differ substantially from natural behavior. One example is the juvenile northern pike staying in the upper layers of the rearing tanks near the water surface. Under controlled conditions, this is an advantageous position since it gives the fish a better chance of catching feed; however, in the wild northern pike stay near the bottom among the vegetation that provides them with hiding places from which they wait motionless for prey or chase prey for short distances (Załachowski 2000). Observations indicated that the success of northern pike attacking live fish from hiding places was three-fold higher than when they chased their prey (Turesson and Brönmark 2004). These two strategies were also used when taking granules of commercial feed, which indicates that this behavior is not changed by short-term controlled rearing. On the other hand, it is known that the impact of the rearing conditions of different fish species can manifest to various degrees in the natural environment. Svenning and Borgstrøm (2005) noted that individuals of Arctic charr that had not consumed other fish during controlled rearing, became predators after being released into lakes to the same degree as individuals that had consumed fish earlier. These authors conclude that the tendency toward cannibalism is conditioned by the environment and the availability of potential victims.

Observations of larvae northern pike indicate that one of the factors that has a strong influence on their behavior is the availability of places to hide when potential threats occur. Creating artificial hiding places (hanging polypropylene lines in rearing troughs or artificial trees in ponds) resulted in better northern pike growth and survival (Wojcieszak and Wahl 1995). Similarly, Wolska-Neja and Neja (2006) did not observe cannibalism when northern pike larvae were reared in tanks in which various structures had been placed. In turn, Lehtiniemi (2005) confirmed that northern pike exhibited almost no defensive reactions to predators when there was a lack of vegetation, while they hid if hiding places were available. Simultaneously, a substantial decrease was noted in the frequency of these fish staging attacks on zooplankton. In the current studies, the first type of behavior was observed, but no strong reaction was noted to the presence of other fish; to the contrary, at moments of stress, as when the fish were removed from the tanks, the northern pike often gathered together. The lack of such a reaction might have resulted from the similar sizes of the fish in the tanks. It has been confirmed that the defensive reaction of northern pike depends on the size of the threatening predator (Engström-Öst and Lehtiniemi 2004).

Several years of studies confirm that juvenile northern pike reared on feed are useful as stocking material (Szczepkowski et al. 2006b). Their survival until fall in ponds was several or even several tens of times greater than that of larvae (Szczepkowski, unpublished data). Simultaneously, it was confirmed that the effectiveness of stocking might depend both on the size of the fry as well as the timing of the stocking. Thus, to fully exploit rearing potential, knowledge of the subsequent results of stocking are necessary. Only the combination of these two elements can make a coherent whole that will permit improving stocks of northern pike in natural aquatic environments. This is even more important since a variety of factors that are biotechnically optimal can later threaten and complicate the subsequent use of this material in stocking programs. The best example of this is the high optimal rearing temperature applied in recirculating systems which never occurs in the natural environment. Thus, further work should concentrate on developing the optimal combination of techniques for the intense rearing of northern pike and its subsequent use as stocking material.

5. Conclusions

1. The experiments indicated that it is possible to effectively rear northern pike juvenile stages under controlled conditions using feed.
2. The greatest problem in rearing northern pike juvenile stages is cannibalism, as was indicated by increased natural losses.
3. Among the factors tested, water temperature, tank type, sorting, and daily feeding ration had the greatest impact on growth, survival, and intensity of cannibalism.
4. The optimal water temperature for the growth of juvenile northern pike was 28°C. Effective rearing can be achieved within the temperature range of 20 to 28°C.
5. Light intensity and the feed granule size had only a slight effect on the rearing of juvenile northern pike, as was indicated by the substantial tolerance of northern pike for fluctuations in these factors.
6. No differences in the growth or survival of the fish were noted during the initial rearing period (1-5 kg m^{-3}) or at the final stocking density (2.9-13.4 kg m^{-3}), which indicates that it is possible to use a relatively high stocking density when rearing northern pike stocking material.
7. During early ontogenic development northern pike behavior changes substantially, and they become increasingly sensitive to external stimuli, which can limit feeding and increase attempts to leap out of the tanks. These behaviors begin to become apparent in fish with body weights of about 150 mg and intensify along with growth.
8. Behavioral changes observed during growth can impact the preferences of young northern pike for certain factors. For example, during the initial rearing period 24 h feeding was optimal, but in older fish (body weight in excess of 5 g) 12 h feeding is preferred.
9. In order to counteract the negative impact of stress and losses during the rearing of juvenile northern pike, the number of manipulations the fish are subjected to should be limited, and measures should be taken to prevent the fish from leaping out of the rearing tanks.
10. Optimum conditions for intense rearing (mainly thermal) might differ from those in the natural environment, which is why determining this parameter for fisheries practice should be founded on the results of the effectiveness of stocking material obtained under controlled conditions.

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7. Streszczenie

Wpływ wybranych czynników abiotycznych i biotycznych na wyniki chowu młodocianych stadiów szczupaka (*Esox lucius* L.) w obiegach recyrkulacyjnych

Celem prowadzonych badań było określenie wpływu wybranych czynników (biotycznych i abiotycznych) na wskaźniki chowu szczupaka, w tym szczególnie na wielkość kanibalizmu oraz prześledzenie ich roli na różnych etapach wczesnego rozwoju tego gatunku. Przeprowadzono dziewięć eksperymentów, w których badano wpływ następujących czynników: temperatury wody, natężenia oświetlenia, dawki i granulacji paszy, dobowego okres żywienia, zagęszczenia obsady, kształtu basenów, sortowania, stosowania nakrywania basenów podchowowych. Materiałem doświadczalnym były larwy i stadia juwenalne szczupaka o średniej masie ciała od 0,012 do 5,7 g uzyskane w wyniku sztucznego rozrodu i wstępnego chowu w obiegach recyrkulacyjnych. Badania przeprowadzono w obiegach recyrkulacyjnych Doświadczalnego Ośrodka Zarybieniowego „Dgał" w Pieczarkach Instytutu Rybactwa Śródlądowego w Olsztynie, w latach 2001-2008. Podczas badań kontrolowano parametry jakości wody (odczyn wody, zawartość tlenu, amoniaku i azotynów). Ryby żywiono komercyjnymi paszami sztucznymi, za pomocą automatycznych karmideł taśmowych. W każdym eksperymencie określano przyrost ryb (SGR), współczynnik pokarmowy (FCR), współczynnik wydajności wzrostowej białka (PER), przeżywalność (S) i kanibalizm u ryb.

Przeprowadzone badania wykazały, że możliwy jest efektywny chów stadiów juwenalnych szczupaka w warunkach kontrolowanych z zastosowaniem paszy. Wyniki eksperymentów wskazują, że czynnikami najbardziej wpływającymi na wyniki chowu szczupaka są temperatura wody, rodzaj zastosowanych basenów, stosowanie sortowania ryb i wielkość dobowej racji paszy. Optymalną temperaturą wody do wzrostu narybku szczupaka jest 28°C, ale efektywny chów może być prowadzony w znacznie szerszym zakresie: od 20 do 28°C.

Stwierdzono, że sortowanie ma pozytywny wpływ na przeżywalność juwenalnego szczupaka, co było związane z niższym kanibalizmem w grupach sortowanych. Nie miało natomiast istotnego wpływu na wzrost ryb. W badanym zakresie początkowego (1-5 kg m^{-3}) i końcowego zagęszczenia obsady (2,9-13,4 kg m^{-3}) nie stwierdzono różnic we wzroście i przeżywalności ryb, co wskazuje na możliwość stosowania w chowie materiału zarybieniowego szczupaka stosunkowo gęstych obsad.

Wyniki stosowania basenów kwadratowych i rotacyjnych wykazały znacznie większą przydatność kwadratowych. U wszystkich badanych stadiów (0,012 g, 0,23 g i 3,08 g), przy porównywalnym tempie wzrostu ryb w obydwu typach zbiorników, w basenach kwadratowych uzyskano przeżywalności wyższe o 8-14%. Wydaje się, że te różnice mogły być spowodowane odmiennym zachowaniem się ryb w porównywanych basenach. Na końcowe efekty podchowu w mniejszym stopniu oddziaływują długość okresu żywienia i stosowanie nakrywania basenów podchowowych.

Czynniki biotyczne i abiotyczne mogą wpływać zarówno na wzrost, przeżywalność i stopień wykorzystania paszy (temperatura i nakrywanie basenów) lub mogą powodować zmiany przeżywalności i wykorzystania paszy, ale nie wpływają na tempo wzrostu ryb (sortowanie, stosowanie zróżnicowanych dawek paszy). Najmniejszy wpływ na wyniki chowu miało natężenie oświetlenia i wielkość granul zastosowanej paszy, co wskazuje na dużą plastyczność szczupaka wobec tych czynników. Największym problemem wychowu młodocianego szczupaka był kanibalizm, który stanowił nawet do 93% strat całkowitych.

Podczas wczesnego rozwoju ontogenetycznego zaobserwowano duże zmiany behawioru szczupaka polegające na coraz silniejszym reagowaniu na bodźce zewnętrzne, ograniczaniu żerowania i próbach wyskakiwania ryb z basenów. Zmiany te zaczynają się pojawiać u osobników o masie ciała około 150 mg i narastają ze wzrostem ryb. W celu ograniczenia negatywnych skutków zmian zachowania się szczupaka należy ograniczyć liczbę manipulacji związanych z wychowem ryb i stosować zabezpieczanie basenów przed ich ucieczką. Zmiany behawioru obserwowane w czasie wzrostu szczupaka mogą wpływać na preferencje tego gatunku wobec różnych czynników: na przykład optymalną długością okresu żywienia jest żywienie całodobowe w początkowym okresie chowu i 12-godzinny rytm żywienia u ryb starszych (o masie ciała powyżej 5 g). Optymalne warunki podchowu (głównie termiczne) mogą odbiegać od warunków spotykanych w środowisku naturalnym, dlatego ich określenie dla praktycznego zastosowania w podchowalniach powinno być oparte na wynikach efektywności zarybień wychowanego w warunkach kontrolowanych materiału.