ISSN 1995-4255, Contemporary Problems of Ecology, 2024, Vol. 17, No. 2, pp. 208–218. © Pleiades Publishing, Ltd., 2024.
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Comparative Characteristics of the Physiological State of Pikeperch (Sander Lucioperca) from Various Habitat Conditions: Lake (Natural Habitat), Ponds, and Fish Farm Cages

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Received February 20, 2023; revised August 19, 2023; accepted October 2, 2023

Abstract—Studies of the physiological state of 3-year-old pikeperch from a lake (natural habitat), ponds, and fish farm cages show significant differences in the size, mass, biochemical, hematological, and histophysiological parameters of fish. Farmed fish are larger (length 26.2 cm; weight 242.1 g) than lake individuals (27.6 cm and 278.2 g, vs. 23.7 cm and 162.6 g in pond pikeperch) and have higher index values of liver (3.68 vs. 1.42 and 1.03% in lake and pond fish, respectively), gonads (0.73 vs. 0.15 and 0.08%), and abdominal fat (8.61 vs. 1.87 and 2.30%). The chemical composition of the body of farmed fish is characterized by a large quantity of lipids (9.4 vs. 2.5 and 3.6%, respectively) and nitrogen-free extracts (NFEs) (3.4 vs. 2.5 and 2.4%), muscle—protein (21.0 vs. 19.0 and 19.2%), and liver—lipids (26.6 vs. 11.1 and 7.5%, respectively) and NFEs (9.6 vs. 1.9 and 2.5%), as well as low moisture (51.7 vs. 69.3 and 71.5%), protein (11.2 vs. 16.6 and 17.2%), ash (0.9 vs. 1.1 and 1.3%), and vitamin C (67.5 vs. 87.9 and 97.6%) contents. The fatty acid (FA) composition of the muscle lipids of farmed fish is generally comparable to that of lake and pond fish—the main groups of FAs are at a similar level: polyunsaturated FAs in the range of 37.0–40.6% of the total FAs, saturated FAs 25.5–29.6%, and monounsaturated FAs 28.0 and 23.2% in farmed and lake fish and 17.5% in pond fish. The content of arachidonic acid 20:4n-6 in farmed fish is extremely low (1.0 vs. 8.0 and 11.5% of the total FAs). Liver lipids of farmed fish contain a large amount of oleic acid 18:1n-9 (30.3 vs. 16.2 and 15.0% of the total FAs in lake and pond fish) and n-6 polyunsaturated FAs (17.5 vs. 8.4 and 7.1%), in particular, linoleic acid 18:2n-6 (7.0 vs. 1.9 and 0.2%). The blood of farmed fish, compared to pond fish, differs in a lower content of hemoglobin (64.8 vs. 74.8 g/L) and an increased content of immature lymphocytes (11.6 vs. 6.1%) and immature erythrocytes (2.2 vs. 1.1%). The gonads of farmed fish are at stage III of maturity with an average oocyte diameter of 478.9 μm; lake fish has two stages of oocyte maturity—the previtellogenic oocytes of protoplasmic growth, 62.7 μm in size, and significantly larger vitellogenic oocytes of trophoplasmic growth, 227.6 μm. In pond pikeperch, gonads correspond to stage II of maturity and oocytes are 58.3 μm in size. Certain differences in pikeperch from lakes, ponds, and farm conditions are associated with the different conditions in which they are kept and fed.

Keywords: pikeperch, physiological state, chemical composition, hematology

DOI: 10.1134/S1995425524020057

INTRODUCTION

In the context of the declining population of the most valuable fish species in Russia's inland waters, it is urgent is to create broodstocks of these fish in controlled conditions in order to replenish their natural populations. Ichthyological research into aquaculture, in which the morphological, physiological, and biochemical parameters of cultivated objects in comparison with similar parameters of wild fish are considered as a qualitative indicator of the success of their reproduction, develops alongside the intensive development of fish farming. However, there are significant limitations to conducting these studies on valuable fish such as sturgeon, salmon, and whitefish that are associated, first and foremost, with the depressed state of their natural populations and the ban on fishing, including for scientific purposes.

Pike perch *Sander lucioperca* L. is a particularly valuable fish. This species is promising for aquaculture and a suitable object for a comprehensive comparative study of morphophysiological, biochemical, hematological, and other parameters in wild and cultivated fish. Pike perch is widespread in our country, including thanks to acclimatization, which significantly expanded its range from the White Sea to the Amur River basin, and introduction into the Novosibirsk

Reservoir has allowed it to take root in the Ob River and go to its lower reaches, the Ob Bay, i.e., beyond the Arctic Circle (*Atlas*..., 2002). However, despite its widespread distribution, commercial stocks of pike perch are characterized by a widespread decline, and there is also a shortage of planting material for artificial reproduction (Kudersky, 2000; Shurukhin et al., 2016), which indicates the need to develop technology for creating and operating reared pike perch broodstock.

It is known that artificially raised fish, including pike perch, have significant differences from fish from natural reservoirs or ponds in morphometric (Lyutikov and Korolev, 2022), morphophysiological (Arechavala-Lopez et al., 2011; Hard et al., 2000; Lyutikov, 2022), chemical (Ackman and Takeuchi, 1986; Alasalvar et al., 2002; Yildiz et al., 2008; Lyutikov et al., 2022), hematological (Fazio et al., 2013; Parrino et al., 2018; Vylka, 2021), and other parameters. Consequently, the study of the qualitative characteristics of broodstock in aquaculture and their comparison with those of wild fish will make it possible to determine criteria for an objective assessment of the physiological state of cultivated species, which, among other things, is of a practical nature.

The purpose of this work is to study the morphophysiological, biochemical, hematological and histophysiological parameters of 3-year-old pike perch from the lake (its natural habitat), ponds, and fish farm cages. Such a comprehensive study of the physiological state of pike perch from various living conditions/keeping conditions, having a common origin (see Material and Methods), is being carried out for the first time, which determines the novelty of this work.

MATERIALS AND METHODS

The object of study is 3-year-old pike perch raised in the ponds of K.A. Averchenkov's rural fish pond nursery and in the cages of the OOO Forvat fish farm in Lake Sukhodolskoye (Priozersky district, Leningrad oblast), as well as wild specimens caught from the same reservoir. The experimental pike perch raised in ponds and in factory conditions have a common origin with lake fish, because they were obtained from broodstock formed at Forvat from spawners caught from Lake Sukhodolskoye in 2014–2017.

In the cages the fish received artificial Biomar Efico Sigma 840 extruded feed (Denmark) with a protein content of 47% and fat 14%. The fatty acid (FA) composition of feed lipids (the main FAs and their groups) is presented in Table 1. In the ponds, the pike perch fed on natural food and juvenile carp fish specially provided as food. The fish were caught for research from a natural reservoir from October 10 to 17, and from cages and ponds on October 25 and 26, 2021, respectively.

Analytical work was carried out in the aquaculture laboratory of the Russian Federal Research Institute of Fisheries and Oceanography (St. Petersburg branch) (Berg National Research Institute of Lake and River Fisheries), the FA composition of fish muscles and liver was determined at OOO MIP-AMT (St. Petersburg), and histological preparations were prepared at the Department of Zoology and Evolutionary Ecology of Animals of Tyumen State University. The number of studied fish from each group was as follows: for morphophysiological analysis, 25 specimens; biochemical, hematological and histophysiological, 10 each; and FA composition of muscles and liver, 5 each.

Table 1. FA composition of feed used for rearing pike perch in cages, % of the total FA

FA	Biomar Efico Sigma 840
SFA	31.64 ± 1.07
MUFA	35.16 ± 1.41
18:3n-3 α-linolenic	2.82 ± 0.02
20:5n-3 eicosapentaenoic	8.88 ± 0.38
22:6n-3 docosahexaenoic	13.41 ± 0.83
n-3 total	25.20 ± 1.01
18:2n-6 linoleic	6.57 ± 0.34
20:4n-6 arachidonic	0.64 ± 0.03
n-6 total	7.39 ± 0.42
Σ PUFA	32.59 ± 1.17

SFA, MUFA, and PUFA are saturated, monounsaturated, and polyunsaturated FAs, respectively.

The length of the fish was determined to the end of the scale cover; the indices of internal organs (liver, gonads, heart, spleen, and gastrointestinal tract) and cavity fat were determined as a percentage of their mass to the mass of the fish. The fatness coefficient was calculated as the ratio of the mass to the body length of the fish up to the end of the scale cover, raised into a cube.

Using chemical analysis methods, the relative content of moisture, dry matter, and lipids was determined (by the Folcha method), as were protein (by the Kjeldahl method); mineral substances (ash) by burning the sample in a muffle furnace at a temperature of 550°C to a constant mass of ash; NFEs by the calculation method; and vitamin C by a modified method of titrating a vitamin extract in hydrochloric acid with Tillman's reagent (Knyazeva, 1979). To determine these indicators, an integral sample was prepared from several fish samples. The analysis of the FA composition of the body of pike perch was carried out using gas–liquid chromatography. The methodology has been published in detail in our earlier works (Lyutikov, 2022).

To study the hematological parameters, we were guided by the Guidelines for Conducting Hematological Examination of Fish of February 2, 1999, no. 13-4-2/1487. Blood was collected from the tail vein.

The histophysiological analysis of the gonads and liver of 3-year-old pike perch was carried out using

Table 2. Biological characteristics of pike perch from various habitats

Sign	Cages		Lake		Pond	
	$M \pm m$	*Cv*, %	$M \pm m$	*Cv*, %	$M \pm m$	*Cv*, %
Length to end scale cover, cm	$26.2 \pm 0.5^{a, b}$	6.17	27.6 ± 0.4^{b}	4.18	23.65 ± 0.4^{c}	5.18
Weight, g	$242.1 \pm 16.2^{a, b}$	21.17	278.7 ± 10.4^{b}	11.83	162.64 ± 18.1^{c}	35.30
Condition factor, %	$1.25 \pm 0.01^{a, c}$	3.79	$1.33 \pm 0.03^{b, c}$	6.50	1.37 ± 0.10^{c}	21.95
Cavity fat, %	8.61 ± 0.29^{a}	10.75	$1.87 \pm 0.25^{b, c}$	42.07	2.30 ± 0.20^{c}	27.27
Liver, %	3.68 ± 0.21^{a}	17.80	1.42 ± 0.10^{b}	21.39	1.03 ± 0.05^{c}	15.07
Heart, %	$0.15 \pm 0.01^{a, c}$	19.24	$0.20 \pm 0.02^{b, c}$	27.56	0.18 ± 0.01^{c}	24.64
Spleen, %	$0.09 \pm 0.01^{a, b}$	26.58	0.11 ± 0.01^{b}	21.14	0.16 ± 0.01^{c}	25.89
Gonads, %	0.73 ± 0.21^{a}	88.82	$0.15 \pm 0.04^{b, c}$	78.87	0.08 ± 0.02^{c}	72.58
Gastrointestinal tract, %	2.82 ± 0.14^{a}	15.29	4.29 ± 0.40^{b}	29.44	2.17 ± 0.08^{c}	10.95

Here and further: *Cv,* coefficient of variation of the characteristic; values with different letter indices have significant differences at the significance level $p \le 0.05$.

standard histological methods (Lilly, 1969; Mikodina et al., 2009). Thirty germ cells were examined to determine the size of oocytes.

Statistical data processing was performed using the Statisica 6.0 software package. The tables show arithmetic mean values (M), standard error of the mean (m), and coefficient of variability of the trait (*Cv*). Student's *t*-test was used to determine differences between groups; normality of distribution was determined by Pearson's test.

RESEARCH RESULTS

Size–Mass and Morphophysiological Indicators

Three-year-old pike perch cultured in cages are characterized by relatively high size and weight indicators (length 26.2 cm; weight 242.1 g), comparable to those of lake fish (27.6 cm and 278.2 g), and high values of the liver index (3.68%), gonads (0.73%) and cavitary fat (8.61%), significantly exceeding similar values for pike perch from the lake (1.42, 0.15, and 1.87%, respectively) and ponds (1.03, 0.08, and 2.30%) (Table 2). The gastrointestinal tract index in artificially grown fish (2.82%) occupies an intermediate value between this index in pike perch from the lake (4.29%) and ponds (2.17%). Cage fish are distinguished from wild fish by a relatively low heart index (0.15 vs. 0.20%) and fatness coefficient (1.25 vs. 1.33%) and from pond fish by a lower spleen index (0.09 vs. 0.16%). Lake and pond fish differ significantly from each other in the liver (1.42 and 1.03%, respectively) and gastrointestinal tract (4.29 and 2.17%) indices, as well as the spleen index (0.11 and 0.16%).

Biochemical Parameters

Differences in body chemistry are reflected in increased levels of lipids (9.4 vs. 2.5 and 3.6%, respectively) and NFE (3.4 vs. 2.5 and 2.4%) (Table 3). Lake specimens differ significantly from pond specimens in lower body content of dry matter (24.9 and 30.1%, respectively), lipids (2.5 and 3.6%), protein (16.8 and 19.9%), and ash (3.1 and 4.2%).

Muscles of fish from different habitats have similar chemical composition and significantly differ in the relatively high protein content in cage specimens—21.0 vs. 19.0 and 19.2% in fish from lakes and ponds, respectively, as well as in vitamin C content, which is higher in pond fish (42.0%) than in hatchery fish (39.3%) and lake fish (28.4%). In addition, pike perch from the lake contain a higher amount of ash (1.3%) and lower NFE (1.1%) than from ponds (1.2 and 2.1%, respectively (Table 3)).

The liver of pike perch cultured in cages on artificial food differs significantly in all studied biochemical parameters from wild and pond specimens and, in addition to increased fat content (26.6 vs. 11.1 and 7.5%, respectively) and NFE (9.6 vs. 1.9 and 2.5%), is characterized by the lowest moisture content (51.7 vs. 69.3 and 71.5%), protein (11.2 vs. 16.6 and 17.2%), ash (0.9 vs. 1.1 and 1.3%), and vitamin C (67.5 vs. 87.9 and 97.6%). Lake fish differ from pond fish by a lower content of ash in the liver (1.1 and 1.3%, respectively) and NFE (1.9 and 2.5%).

Fatty Acid Composition of Muscle Lipids (% of Total FA)

The dominant class of FAs in muscle lipids in pike perch from various habitats are PUFAs, which have similar values in different groups of fish—37.01–40.60% (Table 4). The main part of polyene FAs is represented by n-3, constituting 23.64% in muscle lipids of lake fish, and 28.83 and 30.59% in pond and cage fish, respectively. The most representative FA of the n-3 PUFA family is docosahexaenoic FA (22:6n-3), which is more abundant in the muscle lipids of hatchery fish (22.09%) when compared to lake and pond fish (11.39 and 12.50%, respectively). Next in quanti-

Table 3. Chemical composition of the body, muscles, and liver of 3-year-old pikeperch (lipids, protein, ash, and NFE determined in raw matter)

Sign	Cages		Lake		Pond	
	$M \pm m$	*Cv*, %	$M \pm m$	*Cv*, %	$M \pm m$	*Cv*, %
	Whole fish (*minced*)					
Moisture, %	$66.7 \pm 1.20^{a, c}$	4.0	75.1 ± 0.59^{b}	1.75	69.9 ± 1.61^{c}	5.15
Dry matter, %	$33.3 \pm 1.20^{a, c}$	8.1	24.9 ± 0.59^{b}	5.27	30.1 ± 1.61^{c}	11.9
Lipids, %	9.4 ± 1.06^{a}	25.3	2.5 ± 0.45^{b}	40.9	3.6 ± 0.32^{c}	20.2
Protein, %	$17.6 \pm 0.45^{a, b, c}$	5.7	16.8 ± 0.55^{b}	7.3	19.9 ± 1.08^{c}	12.1
Ash, %	$2.9 \pm 0.44^{a, b}$	33.7	3.1 ± 0.18^{b}	12.7	4.2 ± 0.37^{c}	19.8
NFE	3.4 ± 0.16^{a}	8.8	$2.5 \pm 0.08^{b, c}$	7.9	2.4 ± 0.05^{c}	6.1
Vitamin C, μg/g	$39.6 \pm 0.79^{a, b, c}$	4.5	$36.4 \pm 0.85^{b, c}$	4.8	41.1 ± 2.03^{c}	11.1
	Muscles					
Moisture, %	$75.4 \pm 0.20^{a, b, c}$	0.5	$77.8 \pm 0.21^{b, c}$	0.5	76.9 ± 0.22^{c}	0.4
Dry matter, %	$24.6 \pm 0.20^{a, b, c}$	1.4	$22.2 \pm 0.21^{b, c}$	1.7	23.1 ± 0.22^{c}	1.4
Lipids, %	$0.8 \pm 0.04^{a, b, c}$	8.6	$0.8 \pm 0.48^{b, c}$	99.3	0.6 ± 0.02^{c}	1.3
Protein, %	21.0 ± 0.21^{a}	1.8	$19.0 \pm 0.47^{b, c}$	4.3	19.2 ± 0.17^{c}	1.2
Ash, %	$1.4 \pm 0.01^{a, b}$	0.7	1.3 ± 0.03^{b}	3.9	1.2 ± 0.03^{c}	3.0
NFE, %	$1.4 \pm 0.01^{a, b}$	1.6	1.1 ± 0.02^{b}	2.9	2.1 ± 0.04^{c}	2.7
Vitamin C, μg/g	$39.3 \pm 1.44^{a, c}$	6.4	28.4 ± 0.20^{b}	1.1	42.0 ± 2.70^{c}	9.1
	Liver					
Moisture, %	51.7 ± 2.39^{a}	8.0	$69.3 \pm 1.08^{b, c}$	2.7	71.5 ± 1.12^{c}	3.2
Dry matter, %	48.3 ± 2.39^{a}	8.6	$30.7 \pm 1.09^{b, c}$	6.1	28.5 ± 1.12^{c}	5.9
Lipids, %	26.6 ± 1.98^{a}	12.9	$11.1 \pm 1.10^{b, c}$	17.2	7.5 ± 1.41^{c}	8.4
Protein, %	11.2 ± 0.24^{a}	3.7	$16.6 \pm 1.38^{b, c}$	14.4	17.2 ± 1.18^{c}	10.6
Ash, %	0.9 ± 0.04^{a}	8.0	1.1 ± 0.04^{b}	11.6	1.3 ± 0.04^{c}	6.5
NFE	9.6 ± 0.26^{a}	4.6	1.9 ± 0.03^{b}	2.1	2.5 ± 0.04^{c}	3.3
Vitamin C, μg/g	67.5 ± 9.20^{a}	23.6	$87.9 \pm 2.77^{b, c}$	5.5	97.6 ± 4.24^{c}	12.4

tative content is eicosapentaenoic FA (20:5n-3), 7.56% in pike perch from the lake, 5.70% from ponds, and 4.56% from cages, and maternal α-linolenic FA (18:3n-3), which is of greater importance in muscle lipids of pond fish: 2.24% vs. 1.62 and 1.52% in hatchery and lake fish.

Another group of PUFAs, n-6, is represented to a greater extent in the muscle lipids of pond and lake fish: 16.77 and 13.37%, and to a lesser extent in hatchery fish: 8.39%. At the same time, the basis of the n-6 family in pike perch from ponds and lakes is arachidonic FA (20:4n-6): 11.51 and 8.04%, respectively, which is significantly more than in pike perch from cages (0.96%). In cage fish, the main FA of the n-6 family is linoleic FA (18:2n-6), amounting to 6.38% and, in lake and pond fish, 2.81 and 2.74%, respectively.

The next class of FAs in terms of quantitative content in the muscles of lake and pond fish are SFAs, 28.49 and 29.57%, respectively, and, in hatchery fish, MUFAs, amounting to 27.97% (Table 4). Among the SFA, the dominant one is palmitic FA (16:0), which in all groups of fish has similar values and is in the range of 18.28–20.61%. The most representative monoenoic FA is oleic acid (18:1n-9), which is significantly more abundant in muscle lipids of hatchery fish—19.70%, relative to lake and pond fish—13.40 and 9.28%, respectively. The next MUFA in quantitative terms is palmitoleic FA (16:1n-7), the content of which in the muscles of lake fish is 5.41%, vs. 3.50 and 3.84% in hatchery and pond fish.

FA composition of liver lipids

In the liver lipids of pike perch from various habitats, the dominant class of FAs are MUFAs, which in cage and lake specimens account for almost half of the total FA, 48.39 and 47.59%, respectively, and, in pond specimens, 37.18% (Table 4). At the same time, oleic FA is the main monoenoic FA in the liver lipids of hatchery fish and amounts to 30.32%, while in lake fish this FA is contained in a much smaller amount, 16.17%, and is comparable in content to palmitoleic

Table 4. FA composition of lipids in the liver and muscles of 3-year-old pike perch, % of the total FA

FA		Cages	Lake	Pond	Cages	Lake	Pond
		Liver			Muscles		
SFA	14:0	2.46 ± 0.53	2.23 ± 0.14	1.72 ± 0.64	1.17 ± 0.35	1.50 ± 0.44	0.74 ± 0.37
	15:0	0.22 ± 0.07	0.32 ± 0.11	2.00 ± 0.43	0.19 ± 0.06	0.41 ± 0.11	0.67 ± 0.13
	16:0	16.06 ± 1.02	17.58 ± 1.25	21.78 ± 2.21	18.28 ± 1.61	18.81 ± 1.12	20.61 ± 1.43
	17:0	0.50 ± 0.08	0.46 ± 0.07	0.32 ± 0.04	0.23 ± 0.03	0.65 ± 0.12	0.92 ± 0.18
	18:0	0.18 ± 0.04	2.77 ± 0.15	3.59 ± 0.63	3.66 ± 0.81	5.23 ± 0.94	5.03 ± 1.02
	20:0	–	–	–	0.15 ± 0.02	0.18 ± 0.02	0.14 ± 0.03
	24:0	0.93 ± 0.22	2.58 ± 0.53	0.25 ± 0.06	1.41 ± 0.35	1.71 ± 0.55	1.46 ± 0.42
	∑	20.36 ± 2.19	26.02 ± 2.50	29.66 ± 1.49	25.51 ± 2.84	28.49 ± 3.12	29.57 ± 3.63
MUFA	16:1n-7	8.70 ± 2.62	18.27 ± 5.63	8.45 ± 2.94	3.50 ± 0.71	5.41 ± 1.11	3.84 ± 1.68
	18:1n-7	9.30 ± 2.46	10.09 ± 2.25	8.18 ± 0.72	2.57 ± 0.33	3.95 ± 0.53	3.79 ± 0.64
	18:1n-9	30.32 ± 7.39	16.17 ± 3.63	15.00 ± 1.62	19.70 ± 5.36	13.40 ± 1.62	9.28 ± 2.12
	20:1n-9	0.07 ± 0.01	3.06 ± 0.88	5.55 ± 1.05	2.20 ± 0.20	0.46 ± 0.10	0.59 ± 0.11
	∑	48.39 ± 4.68	47.59 ± 6.92	37.18 ± 4.16	27.97 ± 3.09	23.22 ± 7.29	17.50 ± 6.19
PUFA	18:2n-3	1.68 ± 0.39	0.52 ± 0.08	5.38 ± 1.16	–	–	–
	18:3n-3 ALC	0.61 ± 0.15	0.07 ± 0.02	3.74 ± 0.82	1.62 ± 0.42	1.52 ± 0.36	2.24 ± 0.55
	18:4n-3	0.60 ± 0.17	0.37 ± 0.08	0.41 ± 0.10	0.41 ± 0.08	0.47 ± 0.12	0.39 ± 0.09
	20:3n-3	–	–	–	0.32 ± 0.06	0.67 ± 0.13	0.68 ± 0.14
	20:5n-3 EPK	0.29 ± 0.03	0.21 ± 0.05	0.25 ± 0.08	4.56 ± 0.72	7.56 ± 1.14	5.70 ± 1.02
	21:5n-3	0.16 ± 0.01	0.16 ± 0.01	3.48 ± 0.43	1.19 ± 0.12	0.72 ± 0.6	0.65 ± 0.6
	22:5n-3	0.50 ± 0.14	0.08 ± 0.02	1.39 ± 0.16	0.31 ± 0.03	1.31 ± 0.14	1.67 ± 0.19
	22:6n-3 DHA	1.06 ± 0.22	2.95 ± 0.59	1.04 ± 0.11	22.09 ± 1.01	11.39 ± 0.61	12.50 ± 1.33
	n3	4.90 ± 0.23	4.36 ± 0.21	15.69 ± 0.44	30.50 ± 1.36	23.64 ± 1.05	23.83 ± 0.92
	18:2n-6 LC	7.01 ± 0.86	1.90 ± 0.14	0.21 ± 0.03	6.38 ± 0.72	2.81 ± 0.45	2.74 ± 0.32
	18:3n-6	0.07 ± 0.01	0.11 ± 0.01	0.42 ± 0.03	0.17 ± 0.01	0.37 ± 0.03	0.44 ± 0.03
	20:2n-6	0.21 ± 0.01	0.09 ± 0.01	0.65 ± 0.04	0.31 ± 0.03	0.19 ± 0.01	0.18 ± 0.02
	20:3n-6	0.08 ± 0.01	0.06 ± 0.01	–	0.07 ± 0.01	0.24 ± 0.01	0.54 ± 0.03
	20:4n-6 ARA	0.14 ± 0.01	0.25 ± 0.02	0.07 ± 0.01	0.96 ± 0.05	8.04 ± 0.56	11.51 ± 0.61
	22:2n-6	0.36 ± 0.02	0.25 ± 0.02	0.10 ± 0.01	0.11 ± 0.01	–	–
	22:4n-6	1.15 ± 0.08	1.67 ± 0.11	0.99 ± 0.06	0.12 ± 0.01	–	–
	22:5n-6	–	–	–	0.27 ± 0.02	1.72 ± 0.11	1.36 ± 0.10
	24:2n-6	3.60 ± 0.52	4.02 ± 0.26	4.65 ± 0.24	–	–	–
	n6	12.62 ± 0.64	8.35 ± 0.31	7.09 ± 0.62	8.39 ± 0.66	13.37 ± 0.89	16.77 ± 0.66
	∑	17.52 ± 0.72	12.71 ± 0.40	22.78 ± 0.92	38.89 ± 2.10	37.01 ± 3.12	40.60 ± 2.96
Unaccounted for		12.33	13.68	10.38	7.63	11.28	12.33
Σ n-3/ Σ n-6 PUFA		0.38	0.52	2.21	3.64	1.77	1.72
18:3n-3/18:2n-6		0.09	0.04	17.81	0.25	0.54	0.82
16:0/18:1n-9		0.53	1.09	1.45	0.93	1.40	2.22

Notes: A hyphen indicates less than 0.05%.

FA—18.27%. In pond fish, oleic and palmitic acids are 15.00 and 8.45%, respectively.

The second position in terms of content in the liver lipids of pike perch is occupied by SFA, which in fish from cages amount to 20.36%, from the lake 26.02%, and from ponds 29.66%. Among the SFA, the most representative is palmitic FA, which is less in the liver lipids of hatchery and lake fish, 16.06 and 17.58%, and more in pond fish, 21.78%.

The least representative class of FAs in liver lipids in pike perch from different habitats is PUFA, ranging from 12.71% in lake specimens to 22.78% in pond fish; cage fish occupy an intermediate value for this indicator, 17.52% (Table 4). At the same time, the largest

Table 5. Hematological parameters of 3-year-old pike perch reared in cages and ponds

Index	Cages	*Cv*, %	Ponds	*Cv*, %
Hemoglobin, g/L	64.8 ± 1.9[a]	6.7	74.8 ± 2.1[b]	8.7
Lymphocytes, %	82.4 ± 1.4[a]	5.3	88.2 ± 1.3[a]	4.8
Large (immature) lymphocytes, %	11.6 ± 0.9[a]	23.6	6.1 ± 1.1[b]	54.6
Neutrophils, %	2.2 ± 0.6[a]	80.0	2.7 ± 0.5[a]	56.3
Monocytes, %	3.8 ± 0.7[a]	57.4	3.1 ± 0.5[a]	53.1
Immature red blood cells, %	2.2 ± 0.5[a]	67.1	1.1 ± 0.2[b]	51.6
White blood cells/500 red blood cells	6.3 ± 0.8[a]	40.8	4.9 ± 0.8[a]	53.1

amount of n-3 PUFAs was noted in the liver lipids of pike perch from ponds, 15.69%; in hatchery and lake fish this figure is significantly lower, 4.90 and 4.36%, respectively. On the contrary, in terms of n-6 PUFA content, the leaders are hatchery specimens, in which this group of acids in liver lipids is 12.62%; in pike perch from lakes and ponds it is 8.35 and 7.09%.

The FA composition of PUFA lipids in the liver in different groups of pike perch is quite diverse. Thus, pond fish have significantly more α-linolenic FA, 3.74%, vs. 0.61 and 0.07% in hatchery and lake fish, respectively (Table 4). Eicosapentaenoic FA in all groups of pike perch is at a low level, 0.21–0.29%; docosahexaenoic FA is dominant in the n-3 PUFA class in the liver lipids of lake fish and amounts to 2.95%, while in cage and pond fish this acid significantly less, 1.05% on average.

Among n-6 PUFAs, the most representative FA in the liver lipids of hatchery fish is linoleic FA, 7.01% (vs. 1.90 and 0.21% in lake and pond fish, respectively); in pike perch from lakes and ponds, the dominant one is 24:2n-6, amounting to 4.02 and 4.65%, respectively, the content of which in cage fish was 3.60%. Arachidonic FA in the liver lipids of all studied groups of fish has a low value and is in the range of 0.07–0.25% (Table 4).

The presence of large amounts of 18:1n-9 and 18:2n-6 FAs in the lipids of the liver and muscles of hatchery fish significantly reduced the ratio indices of total PUFAs of the two n3/n6 families in the liver (0.38 vs. 0.52 and 2.21% in lake and pond fish, respectively) and maternal 18:3n-3/18:2n-6 in the liver and muscles (0.09 vs. 0.04 and 17.81%, and 0.25 vs. 0.54 and 0.82%, respectively), and the most representative saturated and monounsaturated FAs are 16:0/18:1n-9 in the liver and muscles (0.53 vs. 1.09 and 1.45%, and 0.93 vs. 1.40 and 2.22%, respectively) (Table 4). The above indices characterize, among other things, the course and direction of reactions and the intensity of lipid metabolism processes in the body (Nefedova et al., 2020).

In general, the FA composition of lipids in the muscles of pike perch reared in cages reflects the composition of FAs in food lipids, which is confirmed by a high level of correlation—$r = 0.93$. For liver lipids, this dependence is significantly lower, $r = 0.74$, which is explained by the high intensity of FA metabolism in the organ.

Hematological Parameters

Hematological studies carried out on pike perch from cages and ponds (fish from the lake were transferred to research when they were dead) indicate significantly lower levels of hemoglobin in the blood in hatchery fish (64.8 vs. 74.8 g/L) and an increased content of large, or immature, lymphocytes (11.6 vs. 6.1%) and immature erythrocytes (2.2 vs. 1.1%) (Table 5). The remaining parameters did not have significant differences, but there was a tendency to an increase in the content of monocytes (3.8 vs. 3.1%) and leukocytes (6.3 vs. 4.9 leukocytes/500 erythrocytes) in the blood of cage fish.

Results of Histological Studies

Histological studies of gonads made it possible to classify experimental fish into groups depending on habitat/keeping conditions. The gonads of the vast majority of female pike perch from ponds corresponded to stage II of maturity, and the bulk of the oocytes were in the process of protoplasmic growth (Fig. 1.1). The sizes of the oocytes were in the range of 36.4–80.5 μm, with an average value of 58.3 ± 3.3 μm. In the ovaries of lake individuals, the presence of two generations of germ cells was noted: previtellogenic oocytes of protoplasmic growth, 62.7 ± 3.8 μm in size, and significantly larger vitellogenic oocytes of trophoplasmic growth, 227.6 ± 11.2 μm, at different phases of cytoplasmic vacuolization (Fig. 1.2). In some gonads there were areas with oocytes that had undergone resorption (Fig. 1.3). The most developed were the gonads of females raised in cage conditions, in which the bulk of oocytes entered the period of vitellogenesis, which indicates the transition of the gonads to stage III of maturity (Fig. 1.4). The dimensions of the oocytes of hatchery specimens were 478.9 ± 32.6 μm.

Statistically, the sizes of oocytes of protoplasmic growth of pond and lake individuals did not differ, while the oocytes of trophoplasmic growth of lake and hatchery females were significantly different.

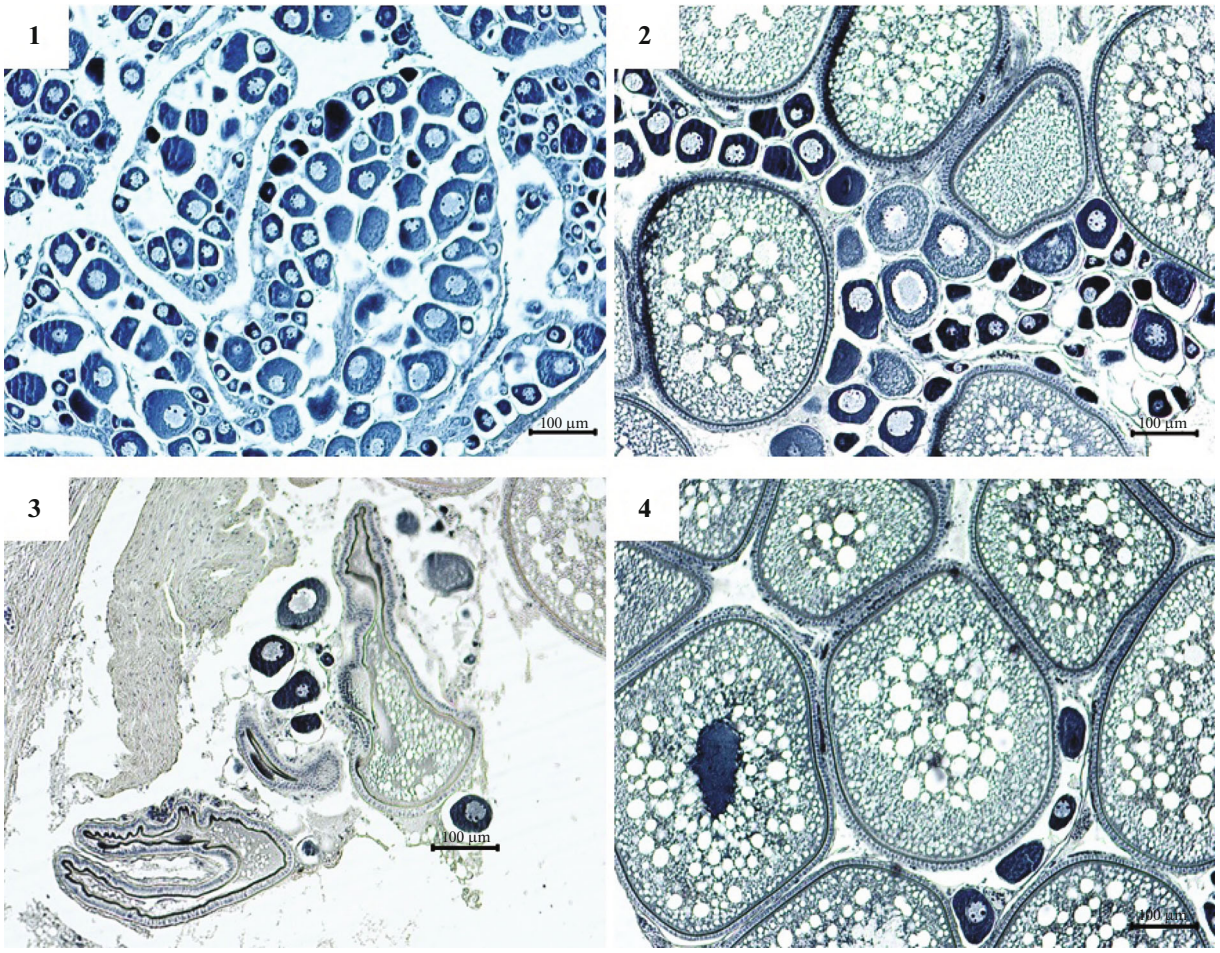

Fig. 1. Fragments of ovaries (×10) of 3-year-old pike perch from various habitats: (1) Ponds: gonads of maturity stage II, protoplasmic growth of oocytes. (2) Lake: gonads of maturity stage II–III, asynchronous development of oocytes, uneven growth of oocytes that have entered the trophoplasmic growth phase (oocytes with varying degrees of vacuolization of the cytoplasm). (3) Lake: resorption of older generation oocytes that have entered the period of trophoplasmic growth. (4) Fish farm cages: gonads of the III stage of maturity. Oocytes that have entered the vitellogenesis phase are characterized by the presence of lumps of yolk in the cytoplasm and droplets of fat scattered between them; boundaries are visible between the cells of the follicular epithelium.

RESULTS AND DISCUSSION

Undoubtedly, the habitat and type of nutrition influence qualitative changes in the morphophysiological, biochemical, and other parameters of artificially farmed fish when compared to wild individuals of the same species. Low physical activity and the use of high-calorie diets lead to the accumulation of excess cavity fat and a significant increase in the liver index of pike perch in cages, on average 4.2 and 3.1 times higher, respectively, than in wild and pond fish. The total body fat content of hatchery specimens is 2.6–3.8 times, and the liver fat content is 2.4–3.5 times greater than that of lake and pond fish (see Table 4). On the contrary, the fat content in the muscles of all the fish we studied is in the range of 0.6–0.8%, which is associated with the peculiarity of lipid metabolism in pike perch—lipids accumulate in the body cavity in the form of visceral fat (Payuta and Flerova, 2019) and, as studies show, in the liver.

The liver of hatchery fish is also characterized by a high NFE content, the level of which is 4.4 times higher than that of pike perch from lakes and ponds, which may be a consequence of excess deposition of reserve fat in the body. For example, in warm-blooded animals with obesity, the level of free FAs in plasma increases for a long time and insulin secretion is suppressed, which, in turn, leads to increased levels of glucose in the blood (Boden and Shulman, 2002). An increase in glucose levels in the blood plasma of cultured fish may be a consequence of the use of very fatty feeds—for example, diets with 26% fat increased glucose levels in *Takifugu rubripes* Temminck, Schlegel. up to 99 mg/100 mL of blood plasma, and with 6% fat only up to 45 mg/100 mL (Kikuchi et al., 2009). Thus, glucose present in the blood of fish with signs of obesity is deposited in the liver in significantly greater quantities than in individuals whose fat level is normal.

Obesity in hatchery fish may be associated with a decrease in the concentration of vitamin C in the liver, which is 1.3–1.4 times less in pike perch from cages than in lake and pond fish. The participation of vitamin C in the prevention of lipid oxidation is known, and its decrease in the liver may indicate a depletion of the antioxidant function of fish and the onset of oxidative stress in them (Ostroumova et al., 1991, 2020).

One more indicator of peroxide stress in fish is a change in the FA composition of liver lipids with a decrease in the number of n-3 acids and an increase in monoenoic FAs (Lukina, 2014). Based on such indicators, proximity was established in hatchery and lake fish, whose liver lipids containing n-3 PUFA was on average 3.4 times less, and MUFA 1.3 times more than similar indicators for pike perch from ponds (see Table 4). Considering the different diets of fish in cages and the lake, the similarity of the FA composition of liver lipids may be associated with the environment of detention/habitat—fish farm cages installed in Lake Sukhodolskoye, the natural habitat of pike perch, which in recent years has been characterized by a significant deterioration in its ecological condition (Kostyunichev, 2021). The process of activation of lipid peroxidation in the body of fish under the influence reservoir pollution is known from the example oil pollution of the Pechora River, in which the whitefish, in addition to other markers of oxidative stress, also had an increase in the level of MUFA and a decrease in PUFA when compared with fish from the control environmentally safe watercourse (Lukina, 2014). It is known that an increase in MUFA with a predominance of oleic FA in fish reserve fats occurs with a deficiency of PUFA, which compensates for the lack of polyenoic acids and thereby ensures the permeability of cell membranes (Watanabe, 1982). This can also be considered an adaptation process in the fish body when lipid peroxidation is activated.

Another reason for the high content (accumulation) of MUFA, mainly 18:1n-9, in the lipids of the liver and muscles of hatchery fish, may lie in their ability to be easily reserved and mobilized in the body for energy needs (Kopprio et al., 2015). Indeed, MUFAs in fish are of food origin and are an important energy source. In the artificial feeds used in our studies, one-third of the lipids consisted of monoenoic FAs (see Table 1), which is associated with the use in the formulation of rapeseed oil, which contains a lot of 18:1n-9 (up to 60% of the total FA) and 18:2n-6 (about 20% of the total FA) (Ostrikov et al., 2016). Apparently, the increase in 18:1n-9 FA and MUFA in the liver and muscle lipids of hatchery fish in general was influenced, among other things, by the nutritional factor.

The presence of 18:1n-9 and 18:2n-6 in the diet and, as a consequence, in the lipids of the liver and muscles of hatchery fish in large quantities significantly reduced the ratio indices n3/n6, 18:3n-3/18:2n-6, and 16:0/18:1n-9, which indicates the low intensity of the metabolism of FAs in the body of pike perch raised in factory conditions, which is accompanied by the active accumulation of lipids in the liver and body cavity.

Low amounts of arachidonic acid in the muscle and liver lipids in hatchery fish may be a consequence of its low content in the artificial diet—0.64% of the total FA. Another reason for the low content of 20:4n-6 in the body of pike perch from hatchery conditions may be their relatively early puberty, which, according to some authors, contributes to the accumulation of this biologically active in reproductive processes acids in the gonads (Bell and Sargent, 2003).

The ovaries of pike perch reared in cages were at stage III of maturity and were characterized by the uniform maturation of oocytes, the bulk of which entered the period of vitellogenesis (see Fig. 1.4). The sizes of oocytes of hatchery specimens were significantly larger than those of lake and pond fish (478.9 μm). In the ovaries of lake fish, the presence of two different-sized generations of germ cells was noted, II and III stages of maturity (62.7 and 227.6 μm, respectively) (see Fig. 1.2), and oocytes in the process of resorption were also found (see Fig. 1.3). Such asynchrony in the gametogenesis of wild fish can be considered the norm: the development of oocytes of trophoplasmic growth in many fish species in nature is synchronized by the onset of stage IV of maturity, and the presence in the gonads of resorbed eggs that have advanced in development relative to the rest of the mass of oocytes is also a mechanism that ensures the homogeneity of reproductive cells when they reach their definitive size (Dryagin, 1949; Koshelev, 1984). The gonads of pond fish were the least developed, their ovaries were at stage II of maturity (see Fig. 1.1); the oocytes were characterized by the smallest size (58.3 μm), comparable to the oocytes of lake fish at stage II of maturity. In addition, the gonadosomatic index (GSI) of pond fish was 2 times less than that of lake fish and 9 times lower than that of cage specimens. This state of the reproductive system in 3-year-old pike perch reared in ponds can be explained by low feeding activity (in the second half of summer in ponds in the northwest of Russia, there is a depression in the food supply associated with the emergence of adult insects) and, as a consequence, a low growth rate of fish.

The poor development of the food supply, the predominance of invertebrates in the diet, and the low occurrence of prey fish in ponds were accompanied by a decrease in the gastrointestinal tract index in pond fish to 2.17%, which is the lowest among the studied groups of pike perch. Hatchery fish had an intermediate value for this indicator: 2.82 vs. 4.29% for wild fish. The relatively low gastrointestinal tract index in fish from cages is associated with the relatively small size of artificial food granules. It is known that smaller food is digested faster than larger food due to the larger surface area available for digestive enzymes (Barrington, 1957); in addition, modern artificial fish food is pro-

duced by the extrusion method, which makes the food components more accessible for digestion—the digestibility of granules of extruded feed by pike perch at a temperature of 20–22°C takes 32–36 h (Pyanov, 2017) and for bleak *Alburnus alburnus* L. at the same temperature it takes 42 h (Fábián et al., 1963). Consequently, artificial diets that are small in size and easily accessible for digestion and assimilation reduce the energy expenditure of aquaculture fish on digestive processes and do not contribute to the development of a massive gastrointestinal tract, unlike wild fish, whose food consists of larger and more difficult to digest food items.

Feed and housing conditions also affect the hematological parameters of fish. In particular, a decrease in the level of hemoglobin in the blood of cage fish to 64.8 vs. 74.8 g/L in pond fish may be associated with a decrease in the intensity of metabolic processes due to a decrease in their physical activity in industrial conditions, as, for example, was shown earlier in Atlantic salmon *Salmo salar* L. (Ostroumova, 1966). Another reason for a decrease in hemoglobin may be obesity in fish, as was found in the Japanese puffer fish (Kikuchi et al., 2009). Nevertheless, the level of hemoglobin in the blood of the fish we studied was close to the norm established for pike perch from natural populations, 67–71 g/L (Jankowska et al., 2003). A 2× magnification of the number of immature lymphocytes in the structure of white blood of pike perch from cages compared to pond specimens does not have a significant effect on the physiological state of fish due to the lack of functional differences between the two groups of lymphocytes (Zhiteneva et al., 2012).

CONCLUSIONS

A study of the physiological state of 3-year-old pike perch raised in cages on artificial food, in ponds on natural food, and caught from natural conditions indicates significant differences between them. Keeping fish in artificial conditions contributes to their faster growth, and it is significantly faster than the growth of pike perch in ponds and the corresponding growth rate of pike perch in the lake. However, low physical activity and high-calorie diets can lead to signs of obesity in hatchery animals, which is expressed in increased body and liver fat, increased liver and cavity fat indices, the accumulation of carbohydrates in the liver (NFEs), and a decrease in hemoglobin in the blood. A change in the FA composition of muscle and liver lipids towards a decrease in n-3 PUFA and an increase in MUFA (in particular oleic FA), as well as a decreased concentration of vitamin C in the liver, are signs of peroxide stress in the body, which is also typical for pike perch living in the lake.

Despite signs of obesity and processes of activation of lipid peroxidation in the body, the state of the gonads of pike perch from hatchery conditions is ahead of the development of the gonads of pond and wild fish and is characterized by relatively synchronous development of oocytes, which in general is an indicator of the normal physiological state of the body. In this regard, it is necessary to develop reference values that reflect the health status of perch fish in aquaculture, which, given the normal physiological status of the body, will differ significantly from those of fish living in the wild.

The peculiarity of the lipid metabolism of pike perch, according to which the accumulation of fat in the muscles of the fish does not exceed 0.8% (for comparison, the fat content of Atlantic salmon fillets is 12–14% and higher), makes it possible for this species to be used to obtain high-quality dietary fish products.

The results of this work determine the need for further physiological and biochemical studies of fish from wild populations and aquaculture in order to determine the optimal conditions for keeping and feeding cultivated fish, which can help improve the quality of producers and their offspring used for the reproduction of natural stocks of pike perch and commercial aquaculture.

Practical Significance of the Work

These results can be used to develop technology for creating and operating pikeperch broodstock in cages installed in natural reservoirs, which can help expand the capabilities of fish farms that do not have technical means for heating water.

FUNDING

This work was carried out as part of State Task no. 730000F.99.1.BV10AA00006, topic no. 31.3 "Development of Technological Documentation for Model Farms for Obtaining Juveniles and the Commercial Rearing of Fish That are Promising Aquaculture Objects," and was partially financed by the OOO Forvat fish farm, where the research was carried out.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The sampling of fish in the current research was performed in accordance with legislation of the Russian Federation. The method corresponds to contemporary recommended practices (EU Directive 2010/63/EU), and was approved by the Animal Ethics Committee of State Research Institute of Lake and River Fisheries (St. Petersburg, Russia).

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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