ISSN 2079-0961, Arid Ecosystems, 2022, Vol. 12, No. 4, pp. 496–504. © Pleiades Publishing, Ltd., 2022.
Russian Text © The Author(s), 2021, published in Aridnye Ekosistemy, 2021, Vol. 27, No. 4(89), pp. 180–190.

A Comparative Assessment of Hematological Indicators of Paddlefish (*Polyodon Spathula* Walbaum, 1792) when Obtaining Mature Oocytes for Food and Fish-Breeding Purposes

N. V. Sudakova[a], *, M. A. Elnakib[b, c], **, and N. I. Rabazanov[d], ***

[a] *St. Petersburg State University of Veterinary Medicine, St. Petersburg, 196084 Russia*
[b] *Astrakhan State University, Astrakhan, 414056 Russia*
[c] *Al-Azhar University, Cairo, Egypt*
[d] *Caspian Institute of Biological Resources, Far Eastern Federal Research Center, Russian Academy of Sciences, Makhachkala, 367000 Russia*
**e-mail: sudakorm@mail.ru*
***e-mail: mahmoud.biotech@azhar.edu.eg*
****e-mail: rnuh@mail.ru*

Received May 17, 2022; revised July 1, 2022; accepted July 1, 2022

Abstract—This study was aimed at assessing the state of reproductive function according to the fish-breeding, hematological, and morphophysiological parameters of the female paddlefish *Polyodonspathula* (Walbaum, 1792), which have repeatedly matured and spawned for food and fish breeding purposes. The work was carried out in 2019–2020 at the BIOS experimental aquaculture complex in the Astrakhan region. It has been shown that the age of the fish, the number of maturations, and the interspawning periods are the most important factors that made it possible to compare the fish-breeding and biological parameters of paddlefish females that matured and spawned in 2020. The stability of the coefficient of fatness explains the degree of activity of the reproductive function of female paddlefish. Significant differences in morphophysiological parameters between age groups, as well as between females from which caviar for various purposes was obtained, have not been shown. The leukocyte formula of the blood of the studied paddlefish females showed a lymphoid character and viscoelastic properties of leukocytes, as well as the cell agglutination noted during the separation of individual blood components. The distribution of leukocyte types differed slightly depending on the age composition ($CV = 35.55$ and 35.23%, $P < 0.05$; $CV = 23.96$ and 30.92%, $P < 0.05$, 23, and 18 years, respectively). The results of hematological studies showed that the younger generation (18 years old) of female paddlefish, from which caviar was obtained for food purposes, is better adapted than the older generation (23 years old), and the development of reproductive function is less susceptible to stress factors during maturation. A different picture is observed for fish that have spawned for fish breeding purposes.

Keywords: female paddlefish, maturation age, interspawning periods, spawn yield, hemoglobin, total serum protein, leukocyte count, reproductive function

DOI: 10.1134/S2079096122040205

The American paddlefish (*Polyodonspathula* Walbaum 1792) has distinctive features, which include high growth rates due to an unusual way of eating food by filtering water containing nutrient organisms, as well as the possibility of obtaining delicious meat and expensive black caviar (Melchenkov and Kanidieva, 2015). In 1974, *Polyodonspathula* larvae were first imported from the United States (Missouri) to Europe in three regions of the USSR: Krasnodar Territory (experimental plant Goryachiy Klyuch), Donetsk region of Ukraine (Donrybokombinat) and Astrakhan region (Ikryaninsky plant; Elnakeeb et al., 2021). For 40 years, scientists have been working on the acclimatization of paddlefish, which resulted in fish breeding and technological standards for rearing paddlefish in ponds and recommendations for breeding (Kozlov, 1998). Paddlefish, like sturgeon, reaches sexual maturity at a later age and larger size than the majority of other fish species (Belyaeva et al., 1997). Sexual maturity of females occurs at 7–14 years (about 6 years in river conditions) with a weight of 10–15 kg and a total length of 107–140 cm (Elnakib et al., 2022). An adequate understanding of the costs of its reproduction is required to appreciate and properly scientifically understand the active growth and development of the paddlefish in aquaculture. The same knowledge is necessary for the conservation of the species, and not only for understanding the evolution of the life cycle.

Fig. 1. The BIOS scientific-experimental complex of aquaculture.

Studies of the reproductive function of paddlefish females matured under artificial conditions and a comparative assessment with indicators of fish of natural origin are very relevant for the further development of the aquaculture of this valuable species.

Hematological parameters of aquaculture fish are indicators of changes in their health, which can be caused by stress, diseases, and rearing conditions affecting productivity (Fazio, 2019; Ahmed et al., 2020). The physiological status of females, determined by a hematological indicator, as one of the most common biomarkers for monitoring homeostasis in fish, especially during spawning periods, can be one of the most reliable assessments of the state of reproductive function (Priborsky and Velisek, 2018).

It is known that the correlation of the fish index is closely related to the hemoglobin level, the number of erythrocytes, and serum protein (Demkina et al., 1977), since they increase with age (Sennikova et al., 2014). In this context, the hemoglobin content is lower in younger fish than in older ones, and it decreases in the interspawning periods (Arkhangelsky and Vikhlyaeva, 1999). The physiological state of the fish and the degree of its change, which is caused by positive or negative factors of external and internal nature, are most fully assessed by blood indicators. In this regard, hematological parameters during the spawning period are significant biological markers that characterize the reproductive function of fish (Melchenkov, 1992).

The purpose of the research is to evaluate the reproductive function of the paddlefish according to fish-breeding, biological, and hematological parameters of repeatedly matured females in ponds when obtaining mature oocytes for food and fish-breeding purposes.

MATERIAL AND METHODS

The work was carried out during two fish-breeding seasons of 2019–2020 at the BIOS Research and Experimental Aquaculture Complex of the Volga-Caspian Branch of the All-Russian Research Institute of Fisheries and Oceanography (Fig. 1).

The 2020 spawning campaign involved 63 paddlefish females, who repeatedly matured and spawned for food and fish farming purposes. Selected spawners were separated by sex and placed separately in 18 concrete pools, which maintained the necessary conditions: water temperature 16–20°C, oxygen content 5.5–6.2 mg/L, pH 7.0–7.4. The following indicators were calculated to assess the reproductive function of paddlefish females: the age of maturation, the number and frequency of maturation, and the yield of spawn according to the formula:

$$B = m/M \times 100\%, \quad (1)$$

where m is the mass of spawn, kg and M is the body mass of the female, kg.

The readiness of females for spawning was determined using the coefficient of polarization of spawn by selecting oocytes using probe samples. To determine the activity of spermatozoa, semen was collected using a Janet syringe or pressure on the abdominal cavity in the direction of the urogenital opening (Mims et al., 2000).

Morphometric indicators (body weight and length) were recorded, and data from electronic tags were read to identify fish. The efficiency of growing paddlefish in ponds was calculated by the Fulton's fatness coefficient (Pravdin, 1966) according to the formula:

$$K = 100 \times (\text{mass, g})/(\text{length, cm})^3, \quad (2)$$

where K is the fatness factor, in percentage.

Studies were carried out to assess the state of the blood according to the leukocyte formula, the concen-

Table 1. Fish breeding and hematological parameters of female paddlefish (*Polyodonspathula*) spawning in 2020

Female no.	Age of first maturation, years	Number of maturations	MNP	Mass of female, kg	Mass of spawn, kg	Spawn yield, % of body mass	Hemoglobin, g/L	TSP, g/L
1st group 1997 (age 23)								
1	15	4	4	15.3	1.7	11	100.9	32.8
2	15	3	4	15.4	1.4	9	97.1	21.8
3	19	2	4	19.6	1.7	9	108.7	17.4
4	23	1	–	13.3	1.5	11	75.5	30.6
5	19	2	4	14.2	1.1	8	98.8	11.9
6	19	2	4	20.2	2.8	14	113.3	29.5
7	15	6	1	15.8	1.3	8	112.9	29.5
8	21	2	2	15.4	1.3	8	90.4	14.1
2nd group 2002 (age 18)								
9	13	2	4	13.8	1.5	11	97.1	19.6
10	9	4	3	15.3	2.0	13	75.9	16.3
11	13	2	4	16.8	Resorb.	–	113.6	31.7
12	15	2	2	14.2	1.8	13	78.7	14.1
13	15	2	2	11.6	1.0	9	81.9	26.2

tration of hemoglobin (Hb), and total serum protein (RSP). The experiment involved two groups of female paddlefish, matured in 2020, from which they received caviar: eight individuals born in 1997 and five individuals born in 2002; and four individuals born in 1997 and five individuals born in 2002 for fish breeding purposes. The following blood parameters were calculated: the number of blood cells, the concentration of hemoglobin, the level of serum proteins, and the leukocyte blood count. Hemoglobin (Hb) concentration was measured from hemoglobin cyanide concentration using a PE-5400 UV/Vis spectrophotometer. The content of total protein in blood plasma was assessed using an IRF-22 refractometer. The leukocytes were classified visually on blood smears using a sliding glass slide (glass size, 24 mm × 50 mm). Blood smears were stained according to Pappenheim using the May-GrünwaldGiemsa (MGG) dye, and the Fish Blood Atlas (Ivanova, 1983) was used to study cell morphology.

Statistical analysis was performed using XLSTAT®2019.2.1 and R academic software (R Core Team 2016). The level of statistical significance set at $p < 0.05$ (95% confidence interval) and tolerance of 0.0001 was used for the analysis. Data are presented as the mean ± standard error. To study the hematological profile of fish, a study of the homogeneity of dispersion (Skewness-Kurtosis test) was performed, taking into account their fluctuations based on the age structure of fish, as suggested by (Sennikova et al., 2014).

RESULTS AND DISCUSSION

Hematological studies were performed on females from which caviar was obtained in two age groups (23 years and 18 years), which revealed significant differences between them.

The results of studies of female paddlefish, from which mature oocytes were obtained for use in food purposes. The physiological state (fish-breeding, biological, hematological, and morphophysiological parameters) was studied in 13 paddlefish females, from which spawn was obtained for processing for food products, and the leukocyte formula of their blood was also studied.

The obtained results of *fish-breeding and hematological* parameters presented in Table 1 indicate that the highest hemoglobin values (113.3 g/L) were shown by female No. 6, which first matured at the age of 19 years and gave the largest amount of caviar during the second maturation: 2.8 kg (yield of 14%). Female paddlefish No. 7 matured six times and also had high hemoglobin values, 112.9 g/L, but a smaller amount of spawn was obtained from her (1.3 kg, yield 8%). The average protein content in the blood serum of the studied females was 23.45 g/L, the highest values were observed in individuals Nos. 1 and 4 (32.8 and 30.6 g/L), the lowest values were in females nos. 2 and 3: 14.1 and 11.9 g/L, below average.

Attention is drawn to the low values of spawn yield, the average indicator of which is 9.8%, which is almost 2 times less than in paddlefish females from the natural habitat in America (15–25%) and 1.5 times lower for acclimatized individuals in an experimental fish

Table 2. The morphophysiological parameters of spawning paddlefish

Statistical indicators	Weight of fish, kg	Fish length, cm	Fulton's fatness coefficient	Hemoglobin concentration, g/L	Total protein in blood serum, g/L
1st group 1997 (23 years old, $n = 8$)					
$M \pm m$	16.15 ± 0.9	144.88 ± 2.1	0.41 ± 0.06	99.7 ± 4.47	23.45 ± 2.9
σ	2.46	5.94	0.17	12.66	8.21
CV, %	15.2	4.1	41.15	12.69	35.01
2nd group 2002 (18 years old, $n = 5$)					
$M \pm m$	14.34 ± 0.9	143.2 ± 2.3	0.45 ± 0.04	89.44 ± 7.06	21.58 ± 3.3
σ	1.92	5.22	0.09	15.79	7.27
CV, %	13.41	3.64	19.99	17.66	33.7

hatchery farm Goryachiy Klyuch of the Krasnodar Territory in Russia (Melchenkov, 1992).

The morphophysiological parameters in the studied paddlefish females (length-to-weight ratio) were low (Table 2). The average value of the fatness coefficient was relatively low, less than one, with a satisfactory physiological state.

The physiological state of the paddlefish born in 2002 was also satisfactory, the average hemoglobin concentration was 89.5 g/L, the minimum values were noted in individuals nos. 10 and 12 (75.9 and 78.7 g/L), and the maximum values were observed in female no. 11 (113.6 g/L), which also had the highest body mass, 16.8 kg. The total protein in the blood serum (TSP) were low and averaged 21.6 g/L, which somewhat differs from the values of the TSP in the first group.

Older female paddlefish (23 years old) had a slightly larger mass (over 16 kg) and matured at 15 and 19 years of age. Their average blood counts were also better than those of the second fish, but the spawn yield rate was higher in females that reached puberty earlier, at 18 years.

The leukocyte formula of the paddlefish females showed that all fish leukocytes are divided into two groups: granulocytes and agranulocytes. Determining the leukocyte types of paddlefish females in two age groups (23 and 18 years old) made it possible to identify significant differences between them (Fig. 2, Table 3). Young forms of neutrophilic granulocytes and eosinophils, which is interpreted as a hyperfunctional element, were observed in the analyzed blood smears. In contrast, different levels of stab granulocytes were found in mature forms in two groups (23 and 18 years old), which is consistent with the published data (Sennikova et al., 2014).

In general, leukocytes of female paddlefish showed a slight positive asymmetric distribution in both

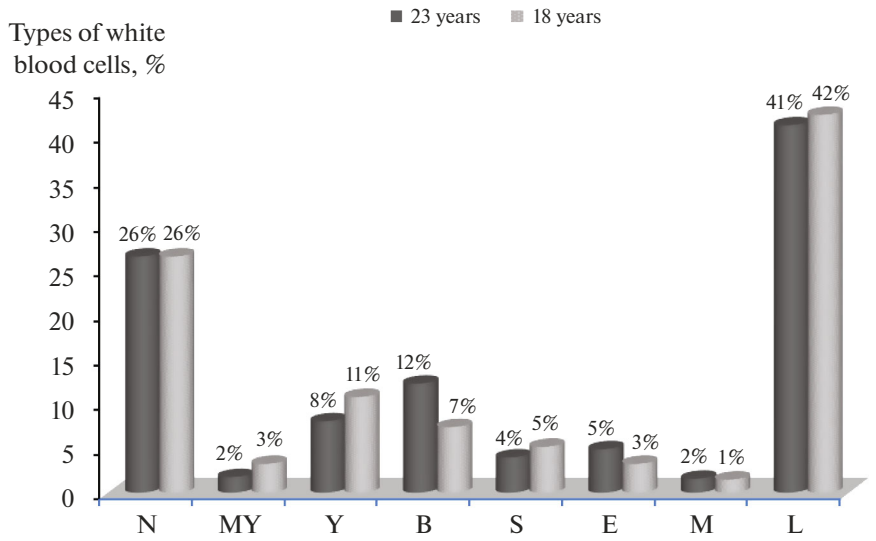

Fig. 2. The ratio of different types of leukocytes in female paddlefish. *Symbols for Fig. 2 and 3:* Y, B, S, young (metamyelocytes), band, and segmented granulocytes; E, eosinophils; M, monocytes; L, lymphocytes; N, neutrophils; MY, myelocyte.

Table 3. The statistical parameters of distributions of different types of leukocytes by age maturation of paddlefish females during the spawning period of 2020

Indicators	Age groups								The norm for a female sturgeon, %*
	1st group 1997 (23 years old, $n = 8$)				2nd group 2002 (18 years old, $n = 5$)				
	$M \pm m$	γ_1	K	CV, %	$M \pm m$	γ_1	K	CV, %	
Neutrophils, %	36 ± 2.91	0.82	–1.21	22.86	36 ± 2.59	–0.19	–2.97	16.08	18.25
Myelocyte	2.7 ± 0.57	0.71	–0.33	50.85	4.4 ± 1.21	0.18	–0.68	61.41	5.25
Metamyelocytes	10.9 ± 1.75	–0.39	–1.17	45.43	14.6 ± 2.54	0.67	0.34	38.93	1.75
Band granulocytes	16.6 ± 1.73	–0.7	–0.2	29.46	10 ± 2.61	0.19	–2.03	58.31	1.0
Segmented granulocytes	5.4 ± 0.63	0.9	–1.06	32.89	7 ± 1.1	0.17	–1.75	34.99	10.25
Eosinophils	6.6 ± 1.08	0.59	0.63	46.3	4.4 ± 0.51	0.4	–0.18	25.91	2.25
Monocytes	2.4 ± 0.48	0.73	–0.74	46.69	2.0 ± 0.32	0	2.0	35.36	0.1
Lymphocytes	56 ± 1.96	–0.8	–0.37	9.92	57.6 ± 2.8	–0.44	–1.39	10.88	67.15
Nucleus displacement							+		
Agglutination			+				+		

Notes on Tables 3 and 6: γ_1, the skewness coefficient, K, the kurtosis coefficient; Grushko, 2009).

groups, which, as a rule, was symmetrical about the median (skewness was 0.23 ± 0.26, 0.12 ± 0.12, $M \pm m$). Kurtosis less than one indicates the proximity of the distribution to the surface (kurtosis was –0.56 ± 0.22, –0.83 ± 0.55, $M \pm m$). Thus, the distribution of blood components does not differ in age composition (CV = 35.55 and 35.23%, $p < 0.05$).

The results we obtained indicate that the lymphocytes predominated in the blood of all the female paddlefish studied, accounting for about or more than half of the total. In some individuals, lymphocytes were reduced to 41–42% due to an increase in the number of neutrophilic granulocytes. In addition to lymphocytes from agranulocytes, there were also monocytes, which accounted for 2–4% of all leukocytes. Among granular leukocytes, the eosinophil content was in the range of 7–4%, although the remaining proportions of leukocyte components indicate no significant differences in age-related immunity and stability, which is expected due to the exposure of all females to stress during their spawning period, contrary to the results published by (Sennikova et al., 2014). The viscoelastic properties of leukocytes showed that the rate of displacement of nuclei during the separation of individual blood components (depending on particle size) is higher than in older fish.

The results of studies of female paddlefish, from which mature oocytes were obtained for fish breeding purposes. The results of studies of fish-breeding and hematological parameters indicate that the paddlefish females were in a satisfactory physiological state (Table 4). The hemoglobin concentration varied: the mean value in older adults was 95.3 ± 6.75 g/L.

The hemoglobin concentration was higher in repeatedly mature females; for example, female no. 2, which matured three times, had Hb = 109.8 g/L while this indicator was one-third lower, 77.3 g/L, in female no. 3, which spawned once. At the same time, the female paddlefish with a high hemoglobin value had the lowest protein content in blood serum, which indicates a decrease in somatic growth and fertility. It was found that the weight of female #2 was 11.2 kg, which was below the average value (13.8 kg). Therefore, it can be assumed that fish weight and serum protein content are associated with reproductive efficiency regardless of hemoglobin concentration, but only as long as it does not fall below the average value (95.3 ± 6.75 g/L). This is confirmed by a large yield of spawn, as evidenced by the data of specimen no. 1 (20%) with a hemoglobin value of 98.8 g/L. The hemoglobin concentration in female no. 3 was low, less than the average value (77.3 g/L) with a large body weight (15.5 kg), and the yield of spawn was lower (10%).

The second group of female paddlefish born in 2002 matured several times, except for fish no. 6. Their interspawning periods were about 4 years, which is very important for assessing reproductive function. The average values of hemoglobin concentration in the blood of fish of this group were 105.26 ± 7.12 g/L, and the content of serum protein was 24.8 ± 1.46 g/L. It should be noted that there is a pattern of influence of fish breeding indicators on the spawn yield. Thus, females Nos. 5, 7, and 8 matured several times at an early age of reaching sexual maturity, on average 12 years, interspawning periods lasted for 4 years, and the average value of their weight was about 14 kg. The percentage of spawn yield was insignificant (12–11%), despite the fact that the hemoglobin concentration was lower than its average value. Obviously, the weight of the fish and the concentration of hemoglobin did not affect

Table 4. The fish breeding and hematological parameters of female paddlefish (*Polyodonspathula*) spawning in 2020

Female no.	Age of first maturation, years	Number of maturations	MNP	Mass of female, kg	Mass of spawn, kg	Spawn yield, % of body mass	Hemoglobin, g/L	TSP, g/L
1st group 1997 (age 23)								
1	23	1	1	15.3	3	20	98.8	19.6
2	20	3	2	11.2	1.1	10	109.8	11.9
3	23	1	1	15.5	1.5	10	77.3	17.4
4	23	1	1	13.3	1.5	11	95.3	21.8
2nd group 2002 (age 18)								
5	14	2	4	13.5	1.68	12	90.7	26.2
6	18	1	1	14.1	1.2	9	117.2	29.5
7	10	5	3	17.4	1.69	10	126.4	23.8
8	14	2	4	13.3	1.45	11	91.4	20.7
9	10	4	3	18.2	н/о	н/о	100.6	23.8

Table 5. The morphophysiological parameters of the spawning paddlefish

Statistical indicators	Weight of fish, kg	Fish length, cm	Fulton's fatness coefficient	Hemoglobin concentration, g/L	Total protein in blood serum, g/L
1st group 1997 (23 years old, $n = 4$)					
$M \pm m$	12.83 ± 0.75	140.25 ± 3.33	0.46 ± 0.01	95.3 ± 6.75	17.68 ± 2.12
Σ	1.51	6.65	0.02	13.5	4.25
CV, %	11.75	4.74	4.78	14.16	24.04
2nd group 2002 (18 years old, $n = 5$)					
$M \pm m$	14.14 ± 0.9	144 ± 3.39	0.47 ± 0.02	105.26 ± 7.12	24.8 ± 1.46
Σ	2.02	7.58	0.03	15.93	3.27
CV, %	14.27	5.27	7.16	15.14	13.2

the reproductive function; on the contrary, the age at which sexual maturity was reached, the number of maturations, and the period between spawning were decisive factors in determining the effectiveness of the reproductive function. It should be noted that female paddlefish no. 6 had high concentrations of hemoglobin and serum protein (117.2 and 29.5 g/L), but she matured later (at 18 years old) and the yield of her spawn was only 9%. Hemoglobin concentration and serum protein content are the main indicators of the physiological state of fish, but not of reproductive function.

The morphophysiological indicators of paddlefish females (Table 5) indicate low parameters of the fatness coefficient (<1), but the content of hemoglobin and TSP in groups of different ages was above average, which indicates a good physiological state of females.

Erythrocytes are represented by mature forms of the erythroid series; these are cells of an ellipsoidal type with a centrally located rounded compacted nucleus of a dark purple color, they contain the respiratory pigment hemoglobin in the cytoplasm. In addition to supplying the body with oxygen and nutrients, they perform enzymatic functions (Elnakib et al., 2021).

Slight changes are traced in red blood cells. Thus, an increase in cell size (anisocytosis) was observed in 13% of fish, and a change in the shape of erythrocytes in the form of deformation, possibly caused by mechanical damage rather than poikilocytosis, was found. A slightly noticeable displacement of the nucleus towards the membrane was observed in single erythrocytes (in 18% of cases). It is known that such changes in the cells of the erythroid series are a reversible process, and, in the future, erythrocytes can separate from each other without being damaged.

The study of the leukocyte blood formula showed that lymphocytes predominated in all females, accounting for about or more than half of all leukocytes. In some individuals, lymphocytes were reduced to 44–49% due to an increase in the number of neutrophilic granulocytes. With respect to metamyelocytes and their

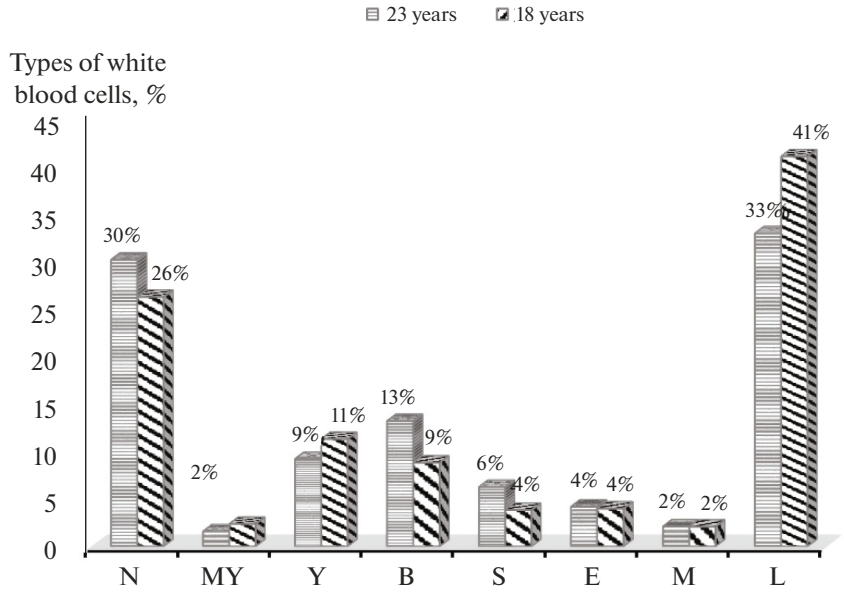

Fig. 3. The ratio of different types of leukocytes in female paddlefish.

stage of development, the percentage was inversely proportional to lymphocytes, which decreased more in late-maturing fish (9%) as opposed to middle-aged fish (11%). Metamyelocytes were the most studied granulocytic cells in all the studied fish. In contrast, pranulocytes and segmented granulocytes, eosinophils, and monocytes were higher in older females than in middle-aged females (23 years, 13 and 6%; 18 years, 19 and 12%). Equal proportions of myelocytes, eosinophils, and monocytes were found in both groups (Fig. 3).

According to R.A. Bullis (1993), the paddlefish leukocyte differential had a much larger range than the 0 to 4% range reported for other fish species and a lower percentage of granulocytes, consistent with published data (Petrie-Hanson and Peterman, 2005). The uniformity of variance results from the Skewness-Kurtosis test are presented in Table 6.

A slightly positive asymmetric distribution of paddlefish uterine stage leukocytes was observed in both groups, apparently symmetrically close to the median (asymmetry was 0.32 ± 0.38 and –0.01 ± 0.18). The kurtosis distribution means that the data tends to be

Table 6. The statistical parameters of the distributions of various types of leukocytes by the age of maturation of female paddlefish during the spawning period, 2020

Indicators	Age groups								The norm for a female sturgeon, %*
	1st group 1997 (23 years old, $n = 8$)				2nd group 2002 (18 years old, $n = 5$)				
	$M \pm m$	γ_1	K	CV, %	$M \pm m$	γ_1	K	CV, %	
Neutrophils, %	43.5 ± 0.87	0	–6	3.98	35.8 ± 3.71	0.36	–1.05	23.15	18.25
Myelocyte	2.25 ± 0.48	–0.85	–1.29	42.55	3.2 ± 0.37	–0.51	–0.61	26.15	5.25
Metamyelocytes	13.25 ± 1.7	1.2	1.98	25.69	15.4 ± 2.04	–0.48	–2.9	29.61	1.75
Band granulocytes	19 ± 2.58	0	–1.2	27.18	12 ± 1.45	–0.73	2	27	1.0
Segmented granulocytes	9 ± 1.78	1.33	1.5	39.54	5.2 ± 1.16	0.5	0.8	49.78	10.25
Eosinophils	6 ± 0	–	–	0	5.4 ± 0.87	0.08	–0.82	36.10	2.25
Monocytes	3 ± 0.71	1.41	1.5	47.14	2.8 ± 0.49	0.61	–3.33	39.12	0.1
Lymphocytes	47.5 ± 1.32	–0.86	–0.29	5.57	56 ± 4.12	0.1	–1.36	16.46	67.15
Nucleus displacement							+		
Agglutination		+					+		

distributed around the median in different directions (0.56 ± 1.04 and -0.91 ± 0.62).

The morphological picture of the Russian sturgeon, which, to a certain extent, is similar to the paddlefish presented by S.B. Pillows (1988) was used for comparison. The proportion of lymphocytes in sturgeon females fluctuated inversely with neutrophils, as in the paddlefish, which is clearly seen in the first group. It should be noted that the number of monocytes was an order of magnitude greater, and the number of eosinophils was 3 times greater than in female sturgeon, which is confirmed by a number of researchers (Grushko, 2009; Ivanova, 1983; Pillow, 1999). Of course, it is necessary to further study the differential number of leukocytes for different age paddlefish at different times of spawning.

Thus, the distribution of leukocyte components differed slightly depending on the age composition. The results showed that young females had a higher rate of nuclear displacement than older females, indicating poor leukocyte characteristics.

CONCLUSIONS

Hematological studies showed that all the studied female paddlefish were in satisfactory physiological condition. Significant differences in the concentrations of hemoglobin and serum protein in the blood were not revealed. The blood obtained from paddlefish females had high hemoglobin values, which indicates a good adaptation of the fish to new conditions of keeping and their considerable endurance. It was found that paddlefish females in the pond conditions of the Astrakhan region reached sexual maturity later, the yield of spawn also turned out to be lower compared to fish from the natural habitat in North America and fish acclimatized in the Krasnodar Territory.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflict of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

REFERENCES

Ahmed, I., Reshi, Q.M., and Fazio, F., The influence of the endogenous and exogenous factors on hematological parameters in different fish species: A review, *Aquaculture International,* 2020, vol. 28, pp. 869–899.

Belyaeva, E.S., Kozlov, A.B., Ermolaev, G.N., and Mal'dov, D.G., Comparison of the activity of digestive tract enzymes of beluga and paddlefish, in *Pervyi kongress ikhtiologov Rossii. Tezisy dokladov, Astrakhan', sentyabr' 1997 g* (Abstr. First Congress of Ichthyologists of Russia, Astrakhan, September 1997), Moscow: Vseross. Nauchno–Issled. Inst. Rybnogo Hozyajstva i Okeanografii, 1997.

Bullis, R.A., Clinical pathology of temperate freshwater and estuarine fishes, in *Fish Medicine,* Philadelphia: WB Sanders Co., 1993, pp. 232–239.

Demkina, H.B., Payusova, A.N., and Tselikova, T.N., Polymorphism of blood serum proteins in paddlefish, in *Pervyi Kongress ikhtiologov Rossii. Tezisy dokladov, Astrakhan', sentyabr', 1997* (Abstr. First Congress of Ichthyologists of Russia, Astrakhan, September 1997), Moscow: Vseross. Nauchno–Issled. Inst. Rybnogo Hozyajstva i Okeanografii, 1997.

Elnakeeb, M.A., Vasilyeva, L.M., and Sudakova, N.V., Evaluate the metabolism responses of cultured paddlefish, *Polyodon spathula* (Walbaum, 1792), towards some ecological stressors in the Volga–Caspian basin using fuzzy modeling control, *Advances in Animal and Veterinary Sciences,* 2021, vol. 9, no. 6, pp. 773–786.

Elnakib, M.A, Vasil'eva, L.M., Sudakova, N.V., and, Anokhina A.Z., Current status of paddlefish aquaculture development, constraints and future prospects in the world and Russia: A brief review, *Rybovodstvo i Rybnoe Khozyaistvo,* 2022, vol. 183, no. 1, pp. 69–79.

Elnakib, M.A., Sudakova, N.V., Vasil'eva, L.M., and Saketova, G.Sh., Research of fish breeding, biological and hematological parameters of paddlefish *Polyodon spathula* (Walbaum, 1792) females, matured in pond conditions in Astrakhan Region, *Rybovodstvo i Rybnoe Khozyaistvo,* 2021, no. 4, pp. 69–79.

Fazio, F., Fish hematology analysis as an important tool of aquaculture: *A review, Aquaculture,* 2019, vol. 500, pp. 237–242.

Grushko, M.P., Features of hematopoiesis in vobla, *Vestnik Astrakhanskogo Gosudarstvennogo Tekhnicheskogo Universiteta. Seriya: Rybnoe Khozyaistvo,* 2009.

Ivanova, N.T., *Atlas kletok krovi ryb: Sravnitel'naya morfologiya i klassifikatsiya formennykh elementov krovi ryb* (Atlas of Fish Blood Cells: Comparative Morphology and Classification of Blood Cells in Fish), Moscow: Legkaya i Pishchevaya Promyshlennost', 1983.

Kozlov, V.I., *Spravochnik fermera–rybovoda* (Fish Farmer's Handbook), Moscow: Vseross. Nauchno–Issled. Inst. Rybnogo Hozyajstva i Okeanografii, 1998, pp. 261–267.

Mel'chenkov, E.A., Experience in lifetime obtaining mature reproductive products of the paddlefish, in *Korma i kormlenie tsennykh ob"ektov akvakul'tury* (Feed and Feeding of Valuable Aquaculture Objects), Moscow: Vseross. Nauchno–Issled. Inst. Presnovodnogo Rybnogo Khozyaistva, 1992, vol. 67, pp. 52–56.

Mel'chenkov, E.A., and Kanid'eva, T.A., Results of research in the field of acclimatization and fishery development of promising aquaculture objects, *Trudy Vseross. Nauchno–Issled. Inst. Rybnogo Hozyajstva i Okeanografii*, 2015.

Mims, S.D., Shelton, W.L., Wynne, F.S., and Onders, R.J., *Production of Paddlefish,* Southern Regional Aquaculture Center, 2000.

Petrie–Hanson, L. and Peterman, A.E., American paddlefish leukocytes demonstrate mammalian–like cyto-

chemical staining characteristics in lymphoid tissues, *J. Fish Biol.,* 2005, vol. 66, no. 4.

Podushka, S.B., Variability in the number of scutes in the Russian sturgeon (*Acipenser gueldenstaedti* Brandt) of the Don River, *Nauchnye doklady vysshei shkoly. Biologicheskie nauki,* 1988, no. 4, pp. 52–57.

Pravdin, I.F., *Rukovodstvo po izucheniyu ryb (preimushchestvenno presnovodnykh)* (Guide to the Study of Fish (Predominantly Freshwater Fish)), Moscow: "Pishchevaya Promyshlennost'", 1966.

Priborsky, J. and Velisek, J., A review of three commonly used fish anesthetics, *Rev. Fish. Sci. Aquacult.,* 2018, vol. 26, no. 4, pp. 417–442.

Sennikova, V.D., Dokuchaeva, S.I., and Sazanov, V.B., Biochemical and hematological indicators of nine and eleven years old bions of paddlefish grown in the pond farms of belarus, *Voprosy Rybnogo Khozyaystva Belarusi,* 2014, no. 30, pp. 129–137.

Translated by M. Shulskaya