Effects of the rearing system of the Russian sturgeon (*Acipenser gueldenstaedtii*) on growth, maturity, and the quality of produced caviar

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Abstract. The present trial was conducted to evaluate two rearing systems (the recirculating aquaculture system "RAS" and a combined technique of RAS and cages) on the growth, puberty, and caviar quality of Russian sturgeon, *Acipenser gueldenstaedtii*. A 3727 two-year-old (1400±61.3 g) fish were raised in RAS and cages, for 180 days, at 20 kg m^{-3}. Growth, feed conversion ratio (FCR), and survival have significantly increased for fish grown in RAS system. Early sex diagnosis of sturgeon (2.5 years old) showed that 97% of the fish grown in cages have clear gonads, while in RAS, it was difficult to determine sex, as the gonads were not visible and had a large content of fat, and less than 10% of fish have gonads. In RAS, the first 15 females gave eggs, aged 5-6 years, and weighing 9.39±0.21 kg. In cages, the first 15 specimens produced eggs aged 6-7 years and weighing 7.25±0.2 kg. Females matured in cages showed superiority in the fecundity and the size of oocytes, along with the natural flavor of eggs compared with those obtained from females ripen in RAS with a specific flavor, which is undesirable.
Key Words: Russian sturgeon, RAS, cages, puberty, fecundity, caviar quality.

Introduction. In worldwide sturgeon aquaculture, Russian sturgeon (*Acipenser gueldenstaedtii*) farming occupies a high proportion because of its superior meat and caviar quality among all sturgeons. With one exception, the beluga sturgeon (*Huso huso*) has caviar with an exquisite taste and superb nutritional quality. Russian sturgeon belongs to the Acipenseridae family, native of the Caspian, Azov, and Black seas. Accordingly, it can be found in the Volga, Kama, Dnieper, Danube, Don, and Kuban rivers. Its fecundity is 59-806 thousand eggs, sometimes up to 1 million ones. Genetically, the Russian sturgeon is a multi-chromosomal (tetraploid) species. The karyotype of the Russian sturgeon has 2n = 247±6 chromosomes. For the biochemical polymorphism of the Russian sturgeon, the proportionality of the polymorphic loci (P) is 25%, while the heterozygotes (H) is 6.6% (Billard & Lecointre 2000).

Universally, the Russian sturgeon is one of the predominant pure species being raised widely for meat and caviar (Aquaculture Russia 2020). The Osetra (Russian sturgeon caviar) harvest from aquaculture accounted for 20% of the global caviar production in 2016 (Bronzi et al 2019). In Russia, this species is the second prevalent behind Siberian sturgeon (*Acipenser baerii*) with a share of up to 35% from the farmed sturgeon harvest. Its production base is full-cycle breeding under controlled conditions through obtaining eggs and sperm via cultivated or domesticated broodstocks, conducting the synthetic insemination, and rearing young fish up to the maturation and producing eggs and/or offspring (Vasilyeva et al 2019).

Globally, there are many techniques and breeding systems used in sturgeon aquaculture. The most prevailing systems are flow-through systems (FS), recirculating aquaculture systems (RAS), cages, mix FS/RAS, and ponds, with shares 36%, 21%, 18%, 11%, and 6%, respectively. Other rearing techniques are mix FS/ponds (4.5%), mix cage/ponds (3.2%), and mix RAS/ponds (0.1%) (Bronzi et al 2019). However, no information is available on the attributes of sturgeon growth using these combined techniques.

Russia is the second-largest producer of meat and caviar from the farmed sturgeon globally; therefore, a wide range of cultural techniques is used. Cages, RAS, ponds, industrial systems, and ranching method are largely present. The share of cages and RAS are up to 65% and 25%, respectively, of the total harvest from cultured sturgeon. In the southern part of Russia, where the natural water temperature is optimal for sturgeon growth more than 200 days annually, cages are widespread due to their lower initial capital investment, lower electricity consumption, easy operation, etc. However, the major drawback is the long duration required for fish maturity, particularly females, and marketing production (Vasilyeva et al 2019).

The most sophisticated technology used in sturgeon aquaculture is RAS. This recent global way in sturgeon farming allows maintaining optimal conditions for sturgeon growth around the year resulting in the shortening of puberty. Under RAS conditions, maturity occurs when Russian sturgeon females are aged 5-7 years with a mass of 5-6 kg, compared to 12-15 years at natural conditions (Brianballe 2010; Wei et al 2013). Nevertheless, a major defect is that the eggs obtained from females grown in RAS up to maturity have an undesirable taste, which reduces the quality and value of this caviar (Doroshov et al 1997; Korchunov 2012).

The combined techniques used in sturgeon farming aim to overcome the long duration required to reach puberty under natural conditions by shortening the maturity period while ensuring a high-quality product from the meat and caviar. Thus, this study makes an attempt to investigate the growth features, access to puberty, and quality of the eggs obtained via Russian sturgeon grown by two methods: RAS, from larvae up to maturation, and combined method of RAS (up 2-3 years old) and then switching to rearing and growing in cages, before puberty and further to the fourth (final) stage of maturity.

Material and Method

Experimental design and work facilities. During the breeding seasons of 2016, this experiment was conducted within a workshop in both tanks equipped with RAS at the scientific and experimental base "BIOS" of the KaspNIPKH Institute (www.Kaspnirh.ru), and cages at the cage fish-breeding company Aquatrade LLC (http://www.rkaquatrade.ru/), in the Astrakhan region of Russia. Prior to starting the experiment, the Russian sturgeon was reared for two years, in the BIOS (reaching an average body weight of 1400±61.3 g), using RAS circular fiberglass tanks (25 m^3 each), and fish density of 20 kg m^{-3}, raised to 45±5 kg m^{-3}, within wintering. For assessing the effect of culturing-system on the reproductive function and quality of eggs, 3727 specimens of Russian sturgeon fish, two-year-old (average body weight of 1400±61.3 g) were reared in both RAS and cages, for 180 days, from April to October 2016. Two treatments (RAS and cage) in triplicates were organized, with a fish density of 20 kg m^{-3} for both. In three RAS circular fiberglass tanks (37 m^3 each), 1584 (528 $tank^{-1}$) specimens of Russian sturgeon fish were stocked. In three cages, the diameter of each (5 x 5 x 2.5 m) with a 16-18 mm mesh size, and water volume of 50 m^3, 2142 (714 $cage^{-1}$) specimens of Russian sturgeon were stocked. Cages were installed in a water canal with a bottom depth up to 4 m, while the cages immersion depth was 2 m. The water source for both cages and RAS tanks was the Volga River.

Feeding regime and fish diets. For feeding fish, during the trial period, a commercial diet with a protein fat ratio of 52/12 from the Danish company Aller-Aqua® was used. During the 180-days trial period, fish were fed two times a day with a daily ration of 1.2% of the total biomass. A random sample of 50 fish was weighed every two weeks to adjust the fish's feed quantity. After the early diagnosis of sex, the selected fish for forming farm-reared broodstocks were kept in cages and fed with a mixture of minced-sprat fish (a small marine fish of the herring family, protein 18.5%, fat 13.1%, ash 1.6%, and moisture 66.8%), and Aller Aqua® diet (45/15; protein/fat ratio) with 70% minced-sprat fish and 30% Aller Aqua® diet.

Assessing water quality parameters. The water quality parameters were monitored daily: pH, water temperature, and dissolved oxygen (DO) content were determined using a Multiline P4 thermal oximeter (Germany). Determinations of nitrite (NO_2-N) and ammonium (NH_4^+) were carried out using digital ammonium and nitrate sensor ISEmax CAS40D (diameter 75 mm, 2.95 inches, Greenwood, IN46143, USA), while nitrate (NO_3-N) was tested weekly using the rapid method by kites according to the Association of Official Analytical Chemists (AOAC 2000).

Growth performance, survival rate, and body composition of Russian sturgeon (2.5 years-old). After finishing the 180-days experimental period, all growth parameters were calculated as follows:

Survival (%) = 100 × (final number/initial number of sturgeon);

Specific growth rate (SGR) = (100 × (ln final mean weight – ln initial mean weight)/days);

Weight gain (WG) = 100 × (average final body weight – average initial body weight) /average initial body weight);

Feed efficiency (FE) = weight gain/feed intake);

Feed conversion ratio (FCR) = feed intake (g)/(final body weight (g) – initial body weight) (g).

The chemical composition of Russian sturgeon flesh 2.5 years-old, is shown in Table 2.

Early identification of sex and maturity stages of Russian sturgeon (2.5-3 years-old). The early determination of the sex ratio of the Russian sturgeon was carried out *in vivo* with the water temperature of 21±10^{o}C, and sex determination was performed using an ultrasonic diagnostic apparatus according to the method of Chebanov (Chebanov & Galich 2010).

Re-diagnosed maturity stage for female farmed broodstocks and receiving the eggs. After 2-3 months of the first ultrasonic diagnosis, females were re-diagnosed to determine the stage of gonad maturity. The maturity stage of Russian sturgeon females and the lifetime of eggs obtained were determined according to Masoudifard et al (2011).

Determining the polarization coefficient (PC). Determination of the PC was carried out according to the Podushka method: several pieces of oocytes were withdrawn from the females using a probe, then processed with formalin, and then they were cut in half, and the relative location of the oocyte nucleus to the edge of the membrane was determined under a microscope; if the distance is less than 10%, the eggs can be fertilized “ripen” (Podushka 1999).

Husbandry of broodstock after receiving eggs. After receiving eggs *in vivo* from the Russian sturgeon females, they were transferred to separate RAS tanks where intensive care and controlled water temperature of 20.5±1.5°C. After receiving the roe, the females were not fed for four days. On the 5th day, they were started to be fed on 0.05% of body weight (BW), and gradually increased from 0.1 to 0.7% of BW during a week. To improve the immune status and prevent stress, vitamin C was administered at a dose of 1 g kg^{-1} of feed for 3-5 days along with B vitamins (multivitamins 1 mL kg^{-1} feed) for seven days. After 2-3 weeks of keeping the Russian sturgeon females in rehabilitation RAS tanks, they were transferred to the cages for re-ripening within 3-5 years (inter-spawning period) (Vasilyeva et al 2019).

Statistical analysis. Statistics were carried out using SPSS 22. Results were presented as mean±SD and tested by one-way ANOVA and Duncan's test with a 5% probability.

Results

Water quality measurements. Results of the water quality parameters measurements in cages and RAS tanks during the period of the study revealed the following: water temperature in cages varied within the normal range required for Russian sturgeon growth (except for 16 days, 2-17 July, when it rose to critical values of 28-30^{o}C) and ranged between 15 and 25^{o}C, generally (Golovanov & Golovanova 2015). In RAS, the water temperature values were relatively stable (16-20°C) throughout the entire fish-growing season and matched to the required values. Variations in the water temperature for cages and RAS within the 180-days rearing experiment of the Russian sturgeon are shown in Figure 1.

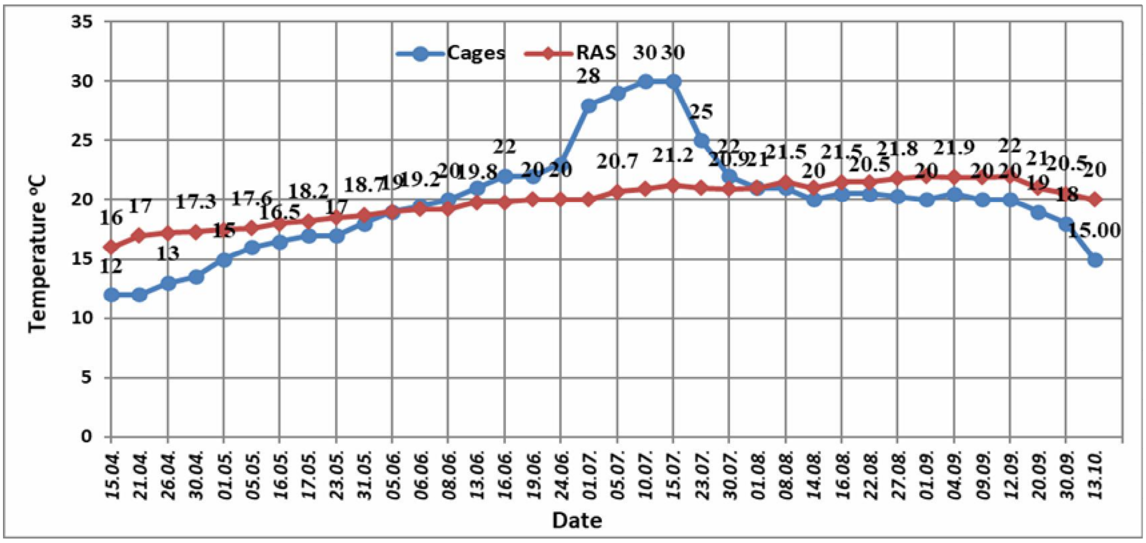

Figure 1. Changes in the water temperature during 180-days of Russian sturgeon rearing trial in cages and RAS tanks.

For DO concentration, in cages, it was generally within the normal range (7-12 mg L^{-1}) (Vasilieva et al 2006); nevertheless, during the period of 3-17 July, raising water temperature to critical values (28-30^{o}C), caused a decrease in the oxygen concentration of DO to 5-6 mg L^{-1}. In RAS tanks, DO content during six-months of the growing period had corresponded to the fish breeding requirements, without significant fluctuations and no sharp drops (Figure 2).

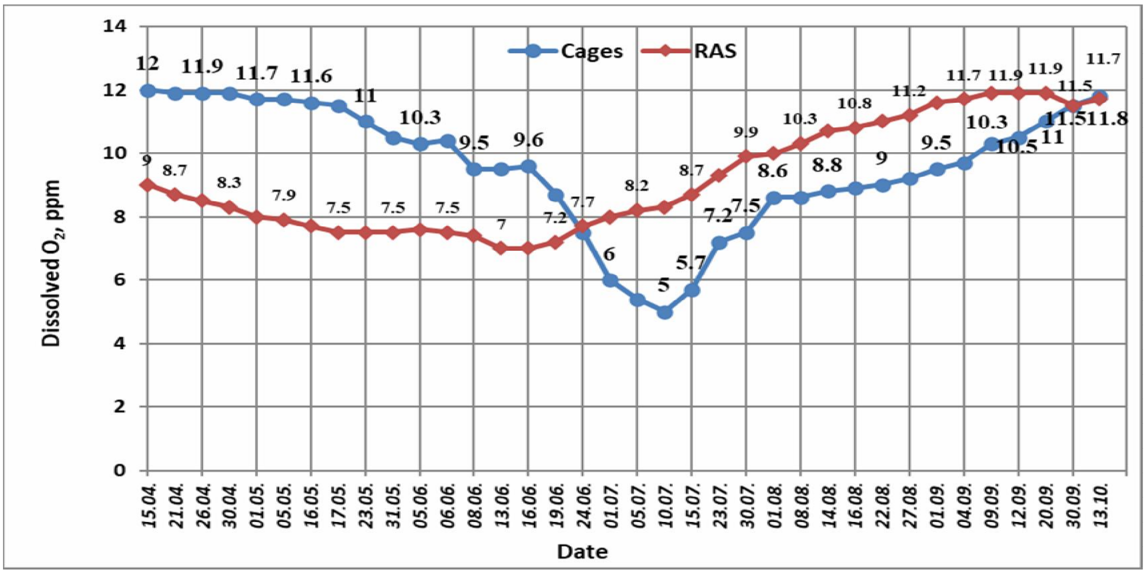

Figure 2. Changes in oxygen content (O_2) during 180-days of Russian sturgeon breeding in cages and RAS tanks.

Regular monitoring of nitrogen components (nitrite, ammonium, and nitrate) in both cages and RAS tanks showed that the values were in the allowed range and recorded (0.008±00.002 and 0.083±0.015), (0.21±0.11 and 0.91±0.87) and (2.1±0.5 and 5.3±1.7) mg L^{-1}, for nitrite, ammonium, and nitrate, in cages and RAS, respectively. The pH values of 7.9±0.3 and 7.5±0.15 were recorded for cages and RAS, respectively.

Growth parameters. Results of Russian sturgeon cultivation with an initial body weight of 1400±61.3 g, for 180-days rearing trial in cages and RAS tanks, revealed RAS's advantage compared to the cages about FBW, WG, FE, and FCR that affected significantly. At the same time, SGR showed a non-significant increase (Table 1).

Table 1

Growth indicators of Russian sturgeon raised 180-days in RAS cages

Studied traits	*Cages*	*RAS*
Initial body weight (IBW) g	1400±61.3	1400±61.3
Final body weight (FBW)g	2480±259^{b}	2900±267^{a}
WG (g fish^{-1})	1080±102^{b}	1500±111^{a}
SGR (% fish^{-1} day^{-1})	4.34±0.56	4.43±0.61
FE (%)	33.32±02^{b}	45.28±0.19^{a}
FCR	3.00±0.12^{b}	2.20±0.16^{a}
Survival (%)	94.9	97.1

The values with a different superscript in the same row differ significantly ($p < 0.05$).

A monthly increase in fish biomass of 250 g fish^{-1} under RAS system was recorded compared with 180 g fish^{-1} for cages. The cages' survival rate was lower (94.9%) than in RAS (97.1%). A comparative assessment for the Russian sturgeon structure's total biomass that has grown for two years and a half in RAS is shown in Figure 3. Based on the final weight, the whole sample was divided into four groups 1800±100 g, 2450±150 g, 3050±150 g, and 4200±100 g, and the largest number of individuals weighted 2.8 to 3.1 kg accounting for 39.4% of the total sample.

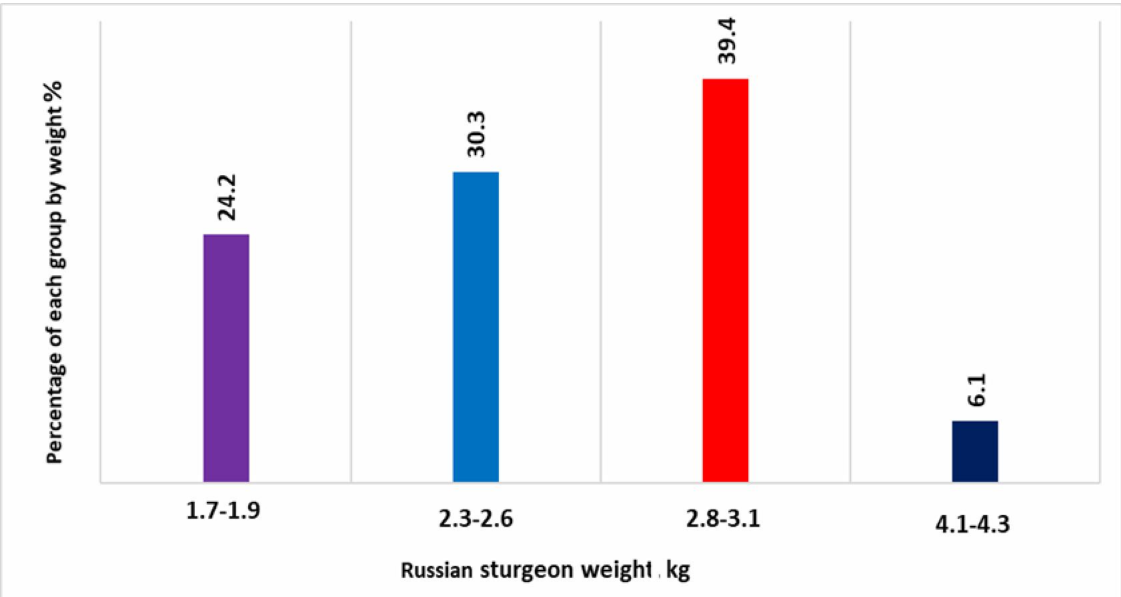

Figure 3. The final weight structure of Russian sturgeon (2.5-years old) grown 180-days in RAS tanks.

In cages, a different manifestation of growth indicators appeared in the Russian sturgeon at the same age due to the natural dynamics of the aquatic environment's thermal regime (Figure 4). The dominant individual weight was 2350±150 g, accounting for 44.1%, and the maximum weight was 3150±250 g, accounting for about 6% of the total number.

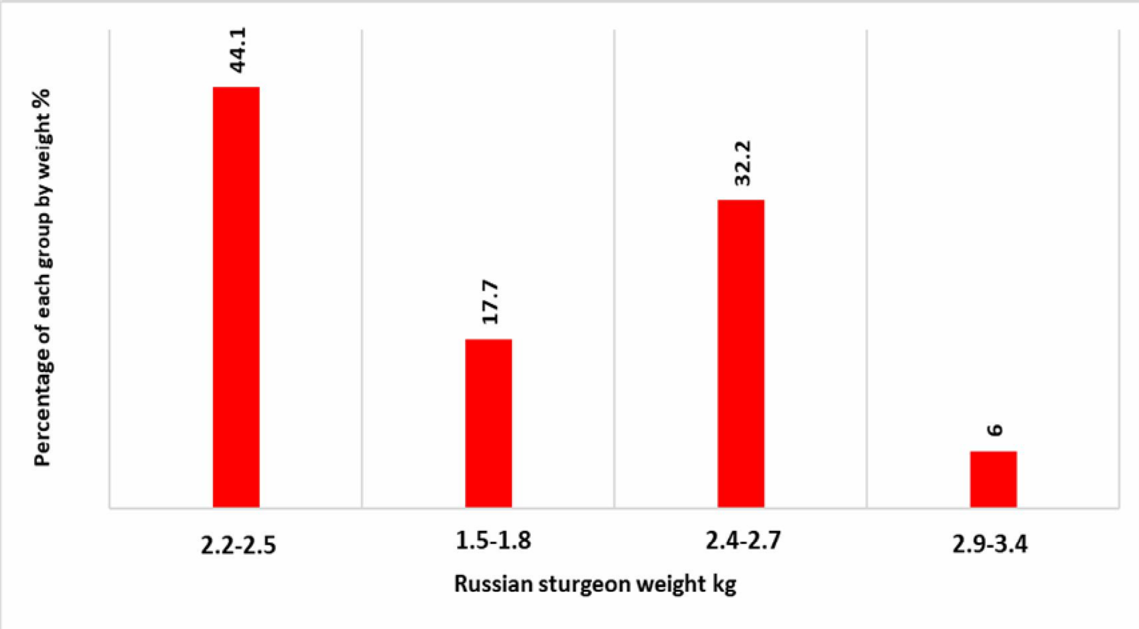

Figure 4. The final weight structure of Russian sturgeon (2.5-years old) grown 180-days in cages.

The chemical composition of Russian sturgeon flesh (2.5-years old). Data on the chemical composition of Russian sturgeon flesh of 2.5 years old is shown in Table 2. The results indicate no statistically significant differences in protein content between fish grown in cages and RAS, while the fat content was significantly higher in fish produced in RAS. As for moisture and ash, they were also affected by the cultivation-method and increased substantially in cages.

Table 2

The chemical composition of Russian sturgeon flesh (2.5-years old)

Culturing-system	*Weight (g)*	*Protein %*	*Fat %*	*Moisture %*	*Ash %*
Initial	1400±61.3	13.5± 3.9	7.8±2.1	76.0±11.8	3.1±0.3
RAS	2 900±75.8	14.4±4.8	15.1±4.5[a]	68.7±11.2[b]	1.8±0.2[b]
Cages	2 480±69.2	14.2±3.7	8.4±2.3[b]	74.7±11.3[a]	2.7±0.1[a]

The values with a different superscript in the same column differ significantly ($p < 0.05$).

Early sex inspection and maturity determination of Russian sturgeon grown in cages and RAS. Early sex inspection of Russian sturgeon (2.5-3 years-old) showed significant variation between fish grown in cages and RAS. In cages, a total of about 2035 specimens were examined, females accounted for 1120 (55%) individuals, 855 (42 %) males were detected, and 61 (3%) of the checked individuals could not be determined because the gonads were not visible due to a large amount of fat. In the diagnosis, 97% of the fish showed clear gonads with longitudinal scanning, with a slight amount of fat along the gonad's edges and in the body cavity. The prevalence of the development of generative tissue was noted.

In RAS, it was difficult to determine sex at that time, as the gonads were not visible and had a large amount of fat, and less than 10% fish was successfully detected. Thus, for optimizing the early determination of Russian sturgeon sex, fish were stocked into separate RAS tanks, the feeding rate was decreased to half, water exchange was increased to 5 L sec^{-1} for 100 kg, and the water temperature was reduced to 7°C. In this mode, the Russian sturgeon was kept for 2-3 months; furthermore, feeding was stopped for two weeks before an ultrasound diagnosis was performed to determine sex, for the second time.

After the first diagnosis for the sex of Russia sturgeon, males that reached a weight of 2-2.5 kg or more were sent for sale. Also, whereas females (1029 specimens) that were distinguished at the 1-2 stages of maturity were stocked into RAS tanks (97 individuals) and cages (932 specimens) for further cultivation and maturation. Broodstocks were formed from the selected females, aged 2.5 years and had an average body weight of 2.5±0.5 kg. Targeted density was 20 kg m^{-3} in cages and 30 kg m^{-3} in RAS.

The re-diagnosis of the maturity stage for farmed broodstock and obtaining eggs. With the second diagnosis within three months, it was found out that in cages, the females had the third stage of gonad maturity, while in RAS, the females had the second stage of gonad maturity. To accelerate the maturation process in cages, fish were kept in optimum conditions. Also, an easily digestible mixture of the minced sprat (70%) and Aller Aqua diet (30%) was introduced for fish; the feeding rate was increased to 1.5% and feeding frequency to 4 times a day. Simultaneously, under RAS conditions, fish continued to be fed with Aller Aqua diet of 52/12 protein/fat, since, in RAS, the wet feed is not recommended in order to prevent contamination of water purification filters.

For Russian sturgeon females that reached puberty, an ultrasound diagnosis was performed again to determine the stage of gonad maturity and further probe biopsy of the developing eggs to estimate the polarization coefficient. Females identified at the fourth stage of maturity and PC not higher than 0.15 were kept for 2-2.5 months at low temperatures (less than 10^oC) without feeding and density of 45±5 kg m^{-3}. After that, within 10-14 days, the fish were gradually bred at the spawning temperatures of 12-14 °C and kept for another three days (Galich 2000). Subsequently, females were injected with pituitary injections to produce eggs. Various drugs are used as injections: Surfagon, carp pituitary, and pituitary extract of sturgeon. Determining the type of preparation and the dosage calculation depends on fish's health status, the PC, water temperature, and drug availability (Kokoza 2004; Tyapugin et al 2013). For example, the females grown in cages pre-injection were performed using the carp pituitary 10%, and then resolution – Surfagon 90%, while for the females from RAS carp pituitary, 10% was applied twice.

Biological indicators of Russian sturgeon females. Results of eggs production from Russian sturgeon females that matured in cages and RAS systems are presented in Table 3. Results obtained showed different values for the leading fish-biological indicators (the age of maturation, females' weight, the release of eggs, and the oocyte size). For the first time, single specimens of Russian sturgeon females exhibited that the maturation stage was discovered at the age of 5-6 years with an average weight of 9 kg in RAS, and 6-7 years with an average weight of 7 kg, in cages. The percentage of the obtained eggs from the first time-matured females in cages was higher than in RAS and amounted to 17.3 and 15.1% of female body weight, respectively. Moreover, the size of eggs was also greater for females matured in cages, so the number of oocytes per 1 g accounted for 53.4 for females reared in cages than 57.2 eggs for RAS reared females.

Table 3

Biological indicators of Russian sturgeon females, matured in RAS and cages

Statistical indicators	*Age of females (year)*	*Body weight (kg)*	*Roe output per one female (kg)*	*Roe output percentage of body weight (%)*	*Number of eggs in 1 g roe*	*Organoleptic properties of caviar*
			RAS, n = 15			
Mean±SD	5-6	9.39±0.21	1.42±0.08	15.1±0.76	57.2±1.36	Has a specific taste
σ		0.80	0.32	2.86	5.08	
CV%		8.48	22.13	18.90	8.87	
			Cages, n = 15			
Mean±SD	6-7	7.25±0.2	1.25±0.6	17.3±0.81	53.4±1.1	Without specific taste (natural)
σ		0.40	0.20	3.10	4.06	
CV%		6.20	18.20	18.2	8.27	

Where: n, number of fish in the sample. Mean, the average body weight of the sample; SD, the variation in the individual values of the sample; σ (sigma), the most commonly used value among statistical dispersion measures for measuring the extent of statistical dispersion in the sample; CV %, the ratio of the standard deviation to the mean.

The chemical composition of eggs. According to the above techniques used to breed Russian sturgeon, the technological qualities of eggs obtained from females grown in both cages and RAS were assessed. The chemical composition of the main components is presented in Table 4. Studying the chemical composition of eggs obtained from the females matured in cages and RAS tanks revealed slight differences. Values were close to a large extent; however, statistically, the protein content had a significant increase in females reared in cages, while carbohydrates increased significantly in eggs obtained from females grown in RAS.

Table 4

The chemical composition of caviar, obtained from Russian sturgeon females reared in cages and RAS system

Moisture (%)	*Protein (%)*	*Fat (%)*	*Carbohydrates (%)*	*Ash (%)*
		RAS		
53.3±0.12	25.6±0.02[b]	13.2±0.21	5.7±0.015[a]	2.2±0.10
		Cages		
53.7±0.19	26.1±0.11[a]	12.8±0.16	4.9±0.013[b]	2.5±0.13

The values with a different superscript in the same column differ significantly ($p < 0.05$).

Discussion. Generally, the available data or literature about their reproduction, feeding, rearing, and growth requirements are scarce for sturgeons. So far, the performed studies are linked to the growth and feeding requirements of larvae and fingerlings. For Russian sturgeon juveniles, sufficient studies are available. They cover growth problems, especially by Russian scientists and others, such as Şener et al (2005) who investigated the effect of dietary lipids on growth and fatty acid composition, and Memiş et al (2007) who studied the effects of different diets on growth parameters and the fatty acid composition. Also, Memiş et al (2009) examined the growth and survival from hatching to artificial nourishment.

In contrast, Roozbehfar et al (2012) tested the effects of *Artemia urmiana* nauplii on growth, while the impact of feeding rates on growth performance and body composition was examined by Andrei et al (2018). However, the development information at the growth-out phase up to maturation is not entirely known for this species. Hence, this study investigated the development of Russian sturgeon aged two years old, which raised to maturity and produced the eggs via cages and RAS.

The optimal temperature for sturgeon growth occurs in spring at the range of 20-26°C. Above 28°C, sturgeons feed slowly or stop feeding. For beluga (*Huso huso*) juveniles and sterlet *(Acipenser ruthenus)* hybrids raised in cages, the optimum temperature recorded for growth was 18-23°C (Műller & Varadi 1984), while for sterlet and hybrid *A. gueldenstaedtii* × *A. baerii*, they were 12-18°C and 19-23°C, respectively (Filipiak et al 1999). According to Mims et al (2002), the required concentration of DO for sturgeon growing is > 5 mg L^{-1}, while the pH range is 6.5-8.5. For the present work, during the 180-days trial period, the water temperature in RAS ranged between 16 and 20°C, while in cages, it generally moved within the recommended values and ranged between 15 and 25°C, except for 16 days (from 2-17 July), when the water temperature rose to critical values of 28-30°C. DO did not come down less than 5 mg L^{-1}, for both systems.

Hung (1991) and Hung et al (1995) reported that depending on water temperature and sturgeon's size, the feeding rate was changed from 0.5 to 4%. For FCR, various values were recorded, 4.9 for Russian sturgeon grown one year, during the second year of age with a stocking density of 10 fish m^{-2}, 4.5 for Siberian sturgeon, and 4.8 for *A. gueldenstaedtii* × *A. baerii* at the same stocking density (Chebanov & Billard 2001). Calculated values of 5.7 and 5.8 were recorded for FCR with Russian sturgeon juveniles at an initial weight of 279.5 ±31.27 g and 271.1±28.21 g, grown 203-days in cages, with SGR of 2.69% day^{-1} (Celikkale et al 2005). In the present study, the growth criteria of Russian sturgeon were affected by the culture method. Since RAS allows creating good conditions for accelerated growth and maturation, the FCR recorded 2.20

and 3.00, while SGR was 4.43 and 4.34 for RAS and cages, respectively. Moreover, the Russian sturgeon survival rate in RAS increased significantly, recording 97.1% versus 94.9% for cages.

Chemical analysis of two-and-a-half-year-old Russian sturgeon flesh showed that the protein content was not affected by the culture method. The fat content was significantly higher for fish reared in RAS (value almost doubled) compared to fish grown in cages, whereas the content of ash had a significant increase for fish raised in cages. Lack of presented data hinders the comparison of these results with others. However, the high increase in fat content for fish raised in RAS can be explained by the fact that the fish grow in non-competitive conditions on food with relatively stable temperatures and little moving. Moreover, one of the reasons is likely reusing water more than once within the system as the rate of water change applied in the RAS system across Russia amounts to 10% of the total volume (weekly or when needed).

The early determining for Russian sturgeon sex aged 2.5 years old, raised in RAS was difficult at that time. The fat content in the fish body was very high (15.1%), approximately two times higher than in cages (8.4%). There was an excessive accumulation of fat in the gonads. In RAS ponds, the fish have little movement, no competition on the food, and no stress; consequently, the reproductive system was not distinguished from performing the sex separation. In RAS, about 10% of individuals were sexually identified with the first diagnosis of sex, comparing with 97% in cages. Thereby, the remaining 90% in RAS were undergoing an intensive care program for 2-3 months to reduce the accumulated fat around the fish gonads before re-identifying their sex (Dettlaff et al 1993; Kokoza 2004).

To obtain the eggs, a broodstock was formed using Russian sturgeon females that weighed 2-3 kg, with a density of 20 kg m^{-3} in cages and 30 kg m^{-3} in RAS. These females were undergoing the care program of the farmed broodstock to reach puberty and produce the eggs. In RAS, the first fifteen specimens of Russian sturgeon females matured and gave eggs for the first time aged 5-6 years, and recording a mean bodyweight of 9.39±0.21 kg. In contrast, the fifteen specimens matured a year later in cages, with an average body weight of 7.25±0.2 kg, less than 2 kg compared to the RAS females. The results can be demonstrated by the fact that the environmental conditions (water temperature 16-22^{o}C, DO 7-12 mg L^{-1}, pH 7.4-8 and ammonium ion, 1-2.5 g N m^{-3}) in RAS accelerated the weight gain and maturity of Russian sturgeon females. On the other side, the cage females had raised in the natural course of water and were affected by the environmental fluctuations, which resulted in delayed maturation and low body weight (Hurvitz et al 2007; Vasilyeva & Sudakova 2014).

However, the females which matured in cages for the first time showed superiority regarding the egg's percentage gained for body weight, 17.3%, and 15.1% of female body weight, for cages and RAS, respectively. Moreover, the eggs obtained from the cage females were distinguished in size, as the number of oocytes per 1 g accounted for 53.4 compared to 57.2 ones for the RAS females. Nevertheless, the substantial difference is the taste of the obtained eggs, where eggs obtained from RAS females have a specific flavor that is not characteristic of the sturgeon product/roe, which reduces valuable product's quality and price. On the other side, the organoleptic indicators of eggs obtained from Russian sturgeon females that mature in cages did not have any specific taste (natural), which is a major advantage (Wei et al 2013; Vasilyeva 2015).

For the eggs' chemical composition, the protein content for eggs obtained from the cages females was higher, while the carbohydrates showed an increase in RAS females' eggs. Generally, the chemical composition values were close to a large extent. Still, the rise of carbohydrates in eggs produced by females grown in RAS is probably due to fat accumulation in the fish body. Insufficiency of the performed studies and experiments on Russian sturgeon, particularly in the pre-puberty stages, has impeded the comparison of obtained results. Thus, there is an urgent need for new studies on Russian sturgeon in all growth phases using various culture systems to satisfy growth rates and good quality for both the eggs' food and flesh.

Conclusions. Depending on the results obtained in this trial regarding growth performance, time of sex ripening, and the quality of caviar acquired, it could be recommended that:

1. To produce sturgeon meat, the RAS technology is favored. It allows us to obtain the sturgeon's marketable weight through the third year of rearing with an average body weight of 2850 gm in meat components compared to open systems.

2. The application of a combined RAS/cages technique in the rearing of the Russian sturgeon could lead to the shortening of puberty time, improve the quality of caviar, increase the percentage of the obtained eggs, and increase the size of oocytes. Eggs obtained from females grown using the combined method and matured in cages within the natural conditions had the best fish biological indicators: a higher percentage of fish mass yield, larger oocytes, and good organoleptic indicators (without a specific taste). Thus, it could be recommended to apply this combined technique that consists of rearing the juveniles in the RAS system for two years where the period of active growth with a predominance of feed metabolism, and then, when puberty starts and the generative growth increases, the fish is taken to grow in cages with a natural course of temperatures.

3. Adequate information about the growth-out phase of the Russian sturgeon up to maturation is not quite known. Therefore, further studies are needed, particularly in combined techniques such as FS/RAS, RAS/cages, and RAS/ponds.

References

Andrei R. C., Cristea V., Crețu M., Dediu L., Docan A. I., 2018 The effect of feeding rate on growth performance and body composition of Russian sturgeon *(Acipenser gueldenstaedtii)* juveniles. AACL Bioflux 11(3):645-652.

Aquaculture Russia, 2020 [Official site of aquaculture in Russia. Aquaculture objects, fish and fish-shaped, sturgeons, Russian sturgeon]. Available at: http://aquacultura.org/science/selektsiya/osetry/russkiy-osetr.php. Accessed: October, 2020. [in Russian]

Association of Official Analytical Chemists (AOAC), 2000 Official methods of analysis. 17th Edition, A.O.A.C., Washington D.C., 2200 pp.

Billard R., Lecointre G., 2000 Biology and conservation of sturgeon and paddlefish. Reviews in Fish Biology and Fisheries 10:355-392.

Brianballe I., 2010 [Guide to aquaculture in closed water supply installations]. Copenhagen, 74 pp. [in Russian]

Bronzi P., Chebanov M., Michaels J. T., Wei Q., Rosenthal H., Gessner J., 2019 Sturgeon meat and caviar production: global update 2017. Journal of Applied Ichthyology 35(1):257-266.

Celikkale M. S., Memis D., Ercan E., Cagiltay F. C., 2005 Growth performance of juvenile Russian sturgeon *(Acipenser gueldenstaedtii* Brandt & Ratzenburg, 1833) at two stocking densities in net cages. Journal of Applied Ichthyology 21(1):14-18.

Chebanov M., Billard R., 2001 The culture of sturgeons in Russia: production of juveniles for stocking and meat for human consumption. Aquatiq Living Resource 14(6):375-381.

Chebanov M. S., Galich E. V., 2010 [Ultrasound diagnostics of sturgeon fish]. Krasnodar: Education-South, 135 pp. [in Rusian]

Dettlaff T. A., Ginsburg A. S., Schmalhausen O. I., 1993 Sturgeon fishes: developmental biology and aquaculture. Springer-Verlag, Berlin, 300 pp.

Doroshov S. I., Moberg G. P., Van Eenennaam J. P., 1997 Observations on the reproductive cycle of cultures white sturgeon, *Acipenser transmontanus*. Environmental Biology of Fishes 48:265-278.

Filipiak J., Czerniejewski P., Sadowski J., Trzebiatowski R., 1999 Comparison of the effects of cage-rearing of sterlet *(Acipenser ruthenus)* and Russian x Siberian sturgeon *(Acipenser gueldenstadetdti x A. baeri)* hybrid fry in cooling water. Electronic Journal of Polish Agricultural Universities - Series Fisheries 2(2):03.

Galich E. V., 2000 [Ecological and morphological features of sturgeon development in the Kuban River at the early ontogenesis of managing the seasonality of their reproduction]. PhD dissertation, Krasnodar Scientific Research Institute of Fish Farm, 159 pp. [in Russian]
Golovanov V. K., Golovanova I. L., 2015 [Temperature optimum and upper-temperature limit of sturgeon fish species]. ATSU Vestnik, Fisheries husbandry 3:110-118. [in Russian]
Hung S. S. O., 1991 Sturgeon, *Acipenser* ssp. In: Handbook of nutrient requirements of finfish. 3rd edition, Wilson R. P. (ed), CRB Press, Boca Raton, FL, pp. 153-160.
Hung S. S. O., Conte F. S., Lutes B. P., 1995 Optimum feeding rate of white sturgeon (*Acipenser transmontanus*) yearlings under commercial production conditions. Journal of Applied Aquaculture 5(1):45-51.
Hurvitz A., Jackson K., Degani G., Levavi-Sivan B., 2007 Use of endoscopy for gender and ovarian stage determinations in Russian sturgeon *(Acipenser gueldenstaedtii)* grown in aquaculture. Aquaculture 270(1-4):158-166.
Kokoza A. A., 2004 [Controlled reproduction of sturgeon fish: monograph]. ASTU publishing house, Astrakhan, Russia, 208 pp. [in Russian]
Korchunov A. A., 2012 [Dynamics of the biochemical composition of the body and sex products of the sterlet *(Acipencer ruthenus* Linnaeus, 1758) from natural populations and cultivated fish. Astrakhan: Publishing House of ASTU]. Series Fisheries №1, pp. 136-143. [in Russian]
Masoudifard M., Vajhi A. R., Moghim M., Nazari R. M., Naghavi A. R., Sohrabnejad M., 2011 High validity sex determination of three years old cultured beluga sturgeon *(Huso huso)* using ultrasonography. Journal of Applied Ichthyology 27:643-647.
Memiş D., Çelikkale M. S., Ercan E., 2007 Effects of different diets on growth performance and body composition of Russian sturgeon *(Acipenser gueldenstaedtii,* Brandt and Ratzenburg, 1833). Journal of Applied Ichthyology 22(s1):287-290.
Memiş D., Ercan E., Çelikkale M. S., Timur M., Zarkua Z., 2009 Growth and survival rate of Russian sturgeon *(Acipenser gueldenstaedtii)* larvae from fertilized eggs to artificial feeding. Turkish Journal of Fisheries and Aquatic Sciences 9:47-52.
Mims S. D., Lazur A., Shelton W. L., Gomelsky B., Chapman F., 2002 Species profile: production of sturgeon. Southern Regional Aquaculture Center Publication No:7200, 8 pp.
Muller F., Varadi L., 1984 Net cage culture of bester (a hybrid of *Huso huso x A. ruthenus)*. In: ADCP/REP/84/21 – Inland Aquaculture Engineering, Aquaculture Development and Coordination Programme, Budapest, 6 June to 3 September 1983. Available at: http://www.fao.org/docrep/X5744E/x5744e0f.htm. Accessed: December, 2003.
Podushka S. B., 1999 [Obtaining caviar from sturgeon with preservation of life of producers]. Scientific and technical Bulletin of INENCO 2:4-19. [in Russian]
Roozbehfar R., Jamali H., Hematian R., 2012 The potential of Russian sturgeon *(Acipenser gueldenstaedtii)* in exploitation of *Artemia urmiana* in comparison with *Daphnia* sp. and its mixture. World Applied Sciences Journal 20(6):776-780.
Şener E., Yıldız M., Savaş E., 2005 Effects of dietary lipids on growth and fatty acid composition in Russian sturgeon *(Acipenser gueldenstaedtii)* juveniles. Turkish Journal of Veterinary and Animal Science 29(5):1101-1107.
Tyapugin V. V., Vasilieva L. M., Yusupova A. Z., 2013 [Interspawning periods of domesticated females of Beluga and Russian sturgeon reared in the cages of fish farm LLC "Beluga" in the Astrakhan region]. Journal of Natural Sciences 1(42):81-86. [in Russian]
Vasilieva L. M., Yakovleva A. P., Scherbatova T. G., Petrushina T. N., Tyapugin V. V., Kitanov A. A., Arkhangelskiy V. V., Sudakova N. V., Astafieva S. S., Fedoseyeva E. A., 2006 [Technologies and biological norms for sturgeon farming in the VIth climate fish farming area]. Sudakova N. V. (ed), VNIRO Publishing, 100 pp. [in Russian]

Vasilyeva L. M., 2015 [Peculiarities of the modern status of the controlled reproduction of sturgeon fishes in the Volga-Caspian basin]. APK-Healthy Food Products 2(6):30-36. [in Russian]
Vasilyeva L. M., Sudakova N. V., 2014 [Biological and technological bases of commodity sturgeon production]. ASU Publishing House, Astrakhan, Russia, 247pp. [in Russian]
Vasilyeva L. M., Elhetawy A. I. G., Sudakova N. V., Astafyeva S. S., 2019 History, current status and prospects of sturgeon aquaculture in Russia. Aquaculture Research 50(4):1-15.
Wei Q., Li L., Du H., Zhang X., Xiong W., Zhang H., et al, 2013 Research on technology for controlled propagation of cultured Chinese sturgeon *(Acipenser sinensis)*. Journal of Fishery Sciences of China 20(1):1-11.

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