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Temperature Factor in the Cultivation of Juvenile Anadromous Sturgeons in Warm-Water Farms

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Abstract

In many fish farms using the warm waters of energy facilities, for long periods, the water temperature can significantly exceed the temperature range favorable for fish rearing. Effective cultivation of juvenile sturgeons in these conditions is a pressing production issue. The purpose of the study is to determine the optimal heat costs for the existing technological stages of growing juvenile sturgeons based on the assessment of the temperature conditions of warm-water farms and their comparison with natural ones. To identify the differences in the specific heat of juvenile fish in the early period of development, based on the authors' research, existing literature data, recommendations and standards, theoretical calculations were carried out for two stages of cultivation (depending on the type and growing conditions). The actual values obtained indicate the optimal stepwise temperature regime for growing the great sturgeon (170 and 9°C/g), the stellate sturgeon (440, 60°C/g) and elevated values for cultivating the Russian sturgeon (420, 45°C/g) in comparison with the optimal calculated values. Based on the results obtained, the following optimal temperature ranges in terms of specific heat can be recommended for production when growing to a mass of 2.5-5.0 g: great sturgeon: 12-18°C; Russian sturgeon: 18-20°C; stellate surgeon: 18-23°C. Subsequent cultivation to a mass of 50-350 g is desirable to be carried out in the optimum zone, i. e.20-26°C.

Keywords: Juvenile sturgeon, Warm-water fish farms, Specific heat, Great sturgeon, Russian sturgeon, Stellate sturgeon

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Introduction

Sturgeons have long been highly valued as a source of valuable meat and highly nutritious caviar, being a delicacy export brand of the former USSR. Regulation of the flow of the lower part of the Volga/Kama cascade and the Don since 1958 led to the loss of spawning grounds by almost 100% for great sturgeon, by 70% for Russian sturgeon, and by 40% for stellate sturgeon. The loss of spawning grounds was partially compensated by the development of artificial reproduction at the constructed fish farms. According to the Food and Agriculture Organization (FAO) statistics, in 1980 the total catch of sturgeon in the world was 28.6 thousand tons, of which 93% had been caught in the USSR (FAO, 2012).

In recent years, no more than 30 tons of sturgeon have been extracted in the Caspian Sea only for artificial reproduction and scientific research. According to expert estimates, the unauthorized seizure in the sea in 2012 amounted to about 380 tons for stellate sturgeon, about 60 tons for great sturgeon, and 800 tons for Russian sturgeon.

With the general trend towards a catastrophic reduction in the natural sturgeon population, the development of their artificial reproduction in aquaculture is of particular importance (FAO, 2020; Naylor *et al.*, 2021; Wang *et al.*, 2021; Willer *et al.*, 2021; Almohmmadi *et al.*, 2022). Today, in many countries in Asia, Europe, and America, the number of fish farms for the production of meat and caviar of sturgeon with high-tech equipment that requires large investments is increasing (FAO, 2012; Brugère *et al.*, 2019; Radojević *et al.*, 2019; Antonucci & Costa, 2020; Su *et al.*, 2020; Arvotec, 2021; Doan *et al.*, 2021; Almuhanna *et al.*, 2022).

In Russia, commercial production of sturgeon in 2018 increased by almost 47% and amounted to about 3.8 thousand tons (Federal Agency for Fisheries, 2019; Mobeen & Dawood, 2022), and the volume of production of aquaculture food caviar, according to the Russian Federal Fisheries Agency (Rosrybolovstvo), is 45-50 tons (The red and the black: the caviar issue, 2019). Siberian sturgeon, bester, and other hybrid forms, as well as sterlet, are grown on a large scale in fish farms to obtain food products. On an unreasonably smaller scale, anadromous species of sturgeon are cultivated, such as Russian sturgeon, great sturgeon, stellate sturgeon, and thorn sturgeon. One of the most important goals for the fisheries industry is the development of commercial sturgeon breeding, which can be achieved most effectively in the conditions of warm-water farms. However, the main distinguishing feature of such enterprises is the peculiarity of the water temperature regime, which is often not characteristic of the living conditions of sturgeon fish in natural reservoirs characterized by significant annual fluctuations of this technologically significant parameter.

Water temperature is the most important controlled abiotic factor that determines the metabolism of cultured fish and their need for a variety of nutrients (Volkoff & Rønnestad, 2020; AL-Jaddawi *et al*., 2021; Ansari *et al*., 2022). An increase or decrease in temperature within acceptable limits causes corresponding shifts in the vital activity of hydrobionts. An increase in temperature increases oxygen consumption and ammonium nitrogen excretion, activates other metabolic processes, enhances the search for, consumption, and digestion of food, as well as accelerates the absorption of dissolved substances from the environment, increases sensitivity to toxicants, and accelerates development and puberty (Anas *et al*., 2020; Antonucci & Costa, 2020; Roh *et al*., 2020; Shettigar *et al*., 2020; Su *et al*., 2020; Verma *et al*., 2021).

In the cold, living organisms fall into a state of rest (suspended animation). The temperature at which this happens is called the "base growth temperature". For different types of fish, this temperature is different; in particular, for sturgeon, it is in the range of ~ 4-7℃ (Knyazev, 2007). For the wintering of anadromous sturgeon spawners in regulated conditions, we have recommended temperature ranges from 2-5 to 4-8 ℃, depending on the species (Bubunets *et al*., 2021a; 2021b).

The conducted studies show that the juvenile fish of many species grow better if the water temperature is unstable (astatic), and fluctuates within the ecological valence of the species with a certain frequency and amplitude that determines the optimal change rate for the thermal factor. At the same time, the amplitude and frequency of oscillations are species-specific. Thus, for juvenile sturgeons, the greatest acceleration of growth (by 1.2-1.7 times) was observed in the ranges of 23 ± 4°C and 25±2°C with an oscillation period of 24 hours (Zdanovich & Pushkar, 1999).

According to Kasimov (1987), at the age of 10-20 days, the optimal temperature for a Russian sturgeon is 18-21°C. Modern studies have established that the temperature optimum for passing the initial stages of the ontogenesis of the Russian sturgeon is in the range of 15-23°C, and to a certain extent depends on belonging to a particular population (Salmanov, 2011). Russian experts in the field of feeding consider the temperature range of 18-25°C as the optimal range for the use of sturgeon starter feeds (Sklyarov, 2008).

Thus, the study of specific temperature conditions of warm-water farms and their impact on the results of various technological stages of sturgeon fish cultivation is very relevant.

The purpose of the study is to determine the optimal heat costs for the existing technological stages of rearing juvenile sturgeons based on the assessment of the temperature conditions of warm-water farms and their comparison with natural conditions.

Materials and Methods

The thermal characteristics of cooling reservoirs and discharge channels of energy facilities depend on the climatic features of the area, the current state of the weather, and the operating mode of the generating capacity of the station. We based the assessment of the temperature regime on the concept developed by Karpevich (1998), which we adapted for warm-water sturgeon farms, assuming the following temperature categories: K-I: winter period, 0.0-7.9°C; K-II: comfort zone, 8.0-19.9°C; K-III: optimum zone, 20.0-26.0°C; K-IV: maximal temperature zone, 26.1-30.9°C; and K-V: lethal zone, ≥ 31°C (Bubunets, 2017; Shaheen *et al*., 2022).

Temperature data were obtained during monitoring of the main abiotic factors in the cultivation of great sturgeon and Russian sturgeon at the fish farm of the Elektrogorskaya state regional power plant (GRES) (Moscow region) and stellate sturgeon at the Mozhaisk Industrial Experimental Fish Hatchery (MPERZ) during the growing season. The resulting digital material was processed according to the above temperature categories **(Tables 1 and 2)**.

The specific heat was determined as the sum of the effective heat in degree days (°C/d) obtained by the completion of a certain stage of growing juvenile sturgeons, in terms of weight gain (g) of the growing fish specimen. To identify differences in the specific heat of juvenile fish and the early period of development, based on our research, existing literature data, recommendations, and standards, we performed theoretical calculations for two stages of cultivation, the first one for the period from switching to active nutrition to a mass of 2.5-3.5 g, and the second one for the further cultivation of fish to a mass of 50-350 g, depending on the species, followed by a comparison of the practical results obtained with the data of several authors.

Results and Discussion

During 145 days of growing juvenile great sturgeon, the average water temperature was 19.9°C (12.0-27.0°C). The temperature range during the cultivation of juvenile Russian sturgeons for 160 days was the most extreme and ranged from 8.0 to 31.5°C with an average value of 23.2°C. The growing of the juvenile stellate sturgeons took place in the most stable conditions at a temperature range of 17.2-23.2°C with an average value of 20.1°C.

Following the existing technological schemes used at farms, the cultivation of juvenile fish born at the farm can be divided into two stages, the first one equaling the time when the fish grows to a mass of 2.5-3.5 g, and the second one covering the further growth to a mass of 50-350 g, depending on the species.

The average water temperature at the first stage of growing larvae and juvenile fish of great sturgeons born at the farm in the pools was 16.1°C (12.0-20.5°C) for 34 days and the total heat was 548.5°C/d. During 50 days of growing Russian sturgeon, the water temperature in the pools varied in the range of 21.5-27.5°C with an average value of 23.5°C and the sum of effective temperatures of 1176.5°C/d. At the first stage of cultivation of the stellate sturgeon, the average daily water temperature was 20.6°C (18.7-23.3°C) with a duration of 52 days and an amount of 1071.6°C/d **(Table 1)**.

Table 1. The amount of accumulated heat, the duration of temperature ranges when growing juvenile fish at the stage from larvae to a mass of 2.5-3.5 g

Species	Duration, days.	Quantity,°C/d	K-II (day/°C/d)	K-III (day/°C/d)	K-II+K-III (day/°C/d)	K-IV (day/°C/d)	K-V (day/°C/d)
Stellate sturgeon	52	1,071.6	13/252.8	39/818.8	52/1,071.6	0/0.0	0/0.0

Russian sturgeon	50	1,176.5	0/0.0	46/1,069.0	46/1,069.0	4/107.5	0/0.0
Great sturgeon	34	548.5	33/528.0	1/20.5	34/548.5	0/0.0	0/0.0

The temperature range of K-II at the first stage of cultivation was 13 days for stellate sturgeon and 33 days for great sturgeon, with the sum of the heat received equaling 252.8 and 528.0°C/d, respectively. The maximum duration and sum of effective temperatures in the optimum zone (K-III) were noted in the growing of Russian sturgeon (46 days at 1,069°C/d) and stellate sturgeon (39 days at 819°C/d), while the minimum values were noted in great sturgeon. The maximal temperature range K-IV was recorded only in Russian sturgeon, which gained 108°C/d in 4 days.

At the second stage, the duration of cultivation was almost the same for all species, equaling 109-111 days, with the maximum amount of accumulated heat in the Russian sturgeon (2,531), and the minimum amount in the stellate sturgeon (2,159.5°C/d). The average water temperature values for the growing period were also close to 19.8-23.0°C, but the boundary values varied: in great sturgeon, they were from 14.5 to 27.0°C; in Russian sturgeon from 8.0 to 31.5°C; and in stellate sturgeon from 17.2 to 21.5°C **(Table 2)**.

Table 2. The amount of received heat, the duration of temperature ranges when growing juvenile fish to a mass of 50-350 g

Species	Duration, days.	Quantity,°C/d	K-II (day/°C/d)	K-III (day/°C/d)	K-II+K-III (day/°C/d)	K-IV (day/°C/d)	K-V (day/°C/d)
Stellate sturgeon	109	2,159.5	51/970.0	58/1,189.5	109/2,159.5	0/0.0	0/0.0
Russian sturgeon	110	2,531.0	32/482.0	26/559.5	58/1,041.5	50/1,427.0	2/62.5
Great sturgeon	111	2,343.3	41/730.4	67/1,531.8	108/2,262.3	3/81.0	3/0.0

Like at the first stage, the most favorable growing conditions were noted in the juvenile stellate sturgeon. The duration of the K-II and K-III temperature ranges was relatively close (51 and 58 days) with the sum of comfortable temperatures equaling 970°C/d and optimal temperatures 1,189.5°C/d. A less favorable temperature regime was observed in juvenile great sturgeon. The duration of the maximal temperature period reached 2.7% of the total growing time, and the duration of comfortable and optimal temperatures equaled 97.3% of the time, of which 62% fell into the optimum zone. The distribution of the total amount of effective temperatures during the cultivation of juvenile Russian sturgeon was characterized by the following indicators: K-II: 19.0%, K-III: 22.1%, K-IV: 56.4%, K-V: 2.5%.

To identify the optimal temperature ranges when growing to a mass of 50-350 g (depending on the species), we studied the obtained indicators of specific heat, namely, °C per 1 g of live weight gain (Karpevich, 1998). Our calculations based on the data of Milstein (1964) on the cultivation of juvenile sturgeons in ponds showed the least stable indicators of heat consumption with the same duration of cultivation and are presented in **Table 3**.

Table 3. Values of specific heat in the cultivation of juvenile anadromous sturgeon

Species	Growing stage	Water temperature,°C		Final weight (average), g		Specific heat,°C/g		Source
		min	max	min	max	min	max	
Stellate sturgeon	1	15	27	0.55	5.1	227	1,999	13
Russian sturgeon	1	15	27	1.2	5.1	227	910	13
Great sturgeon	1	15	25.4	1.2	5.5	199	370	13
Stellate sturgeon	1	22	26	(1.5)		673	796	17
Russian sturgeon	1	22	26	(2.5)		403	477	17
	1	18	20	(3.0)*		213	237	5; 6
	1	18	20	(3.0)		262	292	1; 5; 6
	2	20	26	from 3	to 160	14	19	1; 5; 6
Great sturgeon	1	18	20	(3.0)*		154	172	5; 6
	1	18	20	(3.0)		185	206	1; 5; 6
	1	22	26	(4.0)		252	297	17
	2	20	26	from 3	to 375	7.0	9.1	1; 5; 6
Stellate sturgeon	1	22		(1.5) **		478		7
	1	22		(1.8) **		396		7
Russian sturgeon	1	18	20	(3.8) **		186	207	5
Great sturgeon	1	18	20	(3.0) **		226	251	5
Stellate sturgeon	1	18.7	23.3	(2.5)		437.2		Own data
	2	17.2	22.5	(50)		62		
Russian sturgeon	1	21.5	27.5	(2.9)		416.1		Own data
	2	8	31.5	(82.9)		44.7		

Great sturgeon	1	12	20.5	(3.5)	165	Own data
	2	14.5	27	(350)	8.7	

*in case of receiving reproductive products early;

** juvenile sturgeon cultivation in the pools of a recirculating aquaculture system (RAC)

In our opinion, the lack of the possibility of regulating the temperature of water in ponds and dependence on the development of a natural feed base does not allow us to fully obtain guaranteed and stable cultivation results. Theoretical calculations carried out using existing literature sources have shown a close need for heat for juvenile fish with calculated indicators (Research Institute of Fishery and Oceanography, 2009; Dudko, 2010; Vasileva, 2010; Vasileva, 2010; FAO, 2012). The data calculated based on the results of our research on juvenile great sturgeon are consistent with the "Biotechnological Standards ..., 2010" (Vasileva, 2010), and at the first stage with the "Temporary biotechnical ..., 2009" (Research Institute of Fishery and Oceanography, 2009). The results of growing stellate sturgeon are comparable with the values published in the work by Dudko (2010). The values obtained by calculation for the juvenile Russian sturgeons with an average weight of 2.9 g showed similarities for an increased range of water temperatures (22-26°C) with the data of Chebanov and Galich (2013), and at further stages of cultivation to an average weight of 82.9 g we saw similarities with the results of "Temporary biotechnical ..., 2009" (Research Institute of Fishery and Oceanography, 2009), but with a slight excess of the maximum value caused by the presence of a maximal temperature zone during cultivation.

Conclusion

The analysis of the peculiarities of temperature conditions in the ranges from K-II to K-V made it possible to characterize the temperature changes in the cultivation of juvenile sturgeon fish species in the most complete way. Each species of juvenile fish when growing from larvae that have switched to active nutrition to a mass of 2.5-3.5 g, needs to have the boundaries of optimal temperature ranges adjusted following their physiological and biological needs.

Based on the results obtained, the following optimal temperature ranges in terms of specific heat can be recommended for production when growing to a mass of 2.5-5.0 g: great sturgeon: 12-18°C; Russian sturgeon: 18-20°C; stellar sturgeon: 18-23°C. Subsequent cultivation to a mass of 50-350 g is desirable to be carried out in the optimum zone (K-III, 20-26°C).

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