Results of rearing Siberian sturgeon in cages in the European North

Anna Volkova[1*] and *Larisa* Muraviya[1]

[1]Petrozavodsk State University, 33, Lenina prospect, Petrozavodsk, 185910, Russia

Abstract. The article presents the materials on the study of the influence of stocking density and temperature conditions on the results of growing Siberian sturgeon *(Acipenser Baerii Brandt)* in cages. The material for the study was a group of yearlings of Siberian sturgeon. The planting material was divided into experimental groups with different stocking densities - 70, 132 and 194 pcs/m^2 and placed in cages installed in reservoirs with different temperature conditions - with thermal constants of 1142 and 1580 degree-days. The aim of the work was to evaluate the joint effect of stocking density and water temperature on growth, dynamics of changes in linear-weight and morphometric parameters of sturgeon grown in cages for 97 days. For this purpose, we assessed the fish farming and biological, morphometric parameters and determined the influence of these factors on the morphometric characteristics of sturgeon fingerlings. As a result of the study, a reliable increase in fish weight was noted when kept in groups with a stocking density of 132 pcs/m^2, under different temperature conditions. In the cage with a more optimal temperature of 1580 degree-days, the fish weight by the end of rearing was significantly greater and made 199 g, while the increase in stocking density did not have a negative effect on the rearing results and contributed to a more efficient use of production areas. We noted the highest average daily, relative weight gain and higher values of morphometric indicators in the same group. Single-factor analysis of variance showed that the effect of stocking density on linear-weight and morphometric parameters was low and unreliable.

1 Introduction

One of the most important factors limiting fish growth is water temperature or thermal constants. It has a direct impact on the rate of metabolic processes in the body, promotes the manifestation of the most important indicators of productivity, and allows accelerating the growth and maturation of fish and obtaining fish products at different times.

When growing sturgeons in cages installed in natural water bodies, some factors can be controlled taking into account a number of restrictions. For example, the temperature regime can be changed only during a limited period of the calendar year by placing cages in different parts of the water body (within the permitted water area). In conditions of insufficient heat, sturgeons may have a reduced need for feed, which is typical for heat-

[*] Corresponding author: olubewat@mail.ru

loving fish, and, consequently, their weight gain will decrease. At the same time, when using the cage method, it remains possible to influence the density of fish stocking. This indicator is the most important when using industrial methods of producing commercial products, including products made of sturgeon. We noted that the relationship between fish included in any group is determined by their number, the size of the space, the size of the body, and this is mainly due to the availability of food. The effect of stocking density on fish growth has been repeatedly subjected to detailed analysis. It was found that, as a rule, an increase in stocking density inhibits fish growth [1]. A similar regularity was found in sturgeon in laboratory and industrial conditions [2]. The physiological mechanisms of the effect of stocking density on sturgeons during their transportation [3-4], during rearing of various sturgeon species in pools and RAS [5-6] have been studied in sufficient detail. There is insufficient information on the combined effect of temperature and stocking density on the results of growing Siberian sturgeon during cultivation in cages in the conditions of the northern regions of Russia. This issue has hardly been studied, despite the need to understand the features of sturgeon cultivation using the cage method due to the high value of these aquaculture objects [7].

In this regard, the aim of the work was to evaluate the combined effect of stocking density and water temperature on the growth rate, dynamics of changes in linear-weight and morphometric parameters of Siberian sturgeon when grown in cages in the conditions of the northern regions of Russia. The tasks included:

1. To assess the influence of stocking density and water temperature on fish-breeding biological and morphometric parameters of fingerlings of Siberian sturgeon.
2. Using methods of variation statistics to assess the level of joint influence of stocking density and water temperature on morphometric parameters of fingerlings of Siberian sturgeon.

2 Material and methods

The research was conducted in the Republic of Karelia in a fish farm located in the waters of two reservoirs – Lake Kedrozero and Lizhemskaya Bay of Lake Onega, connected by the Lizhma River and having different temperature regimes due to different depths. The material for the studies was 1621 yearlings of Siberian sturgeon with an average live weight of 18.3 g and a body length of 18 cm. The stocking material was divided into experimental groups with different stocking densities and placed in cages measuring 1.5×1.5 m^2, 1 m deep, installed in reservoirs with different temperature regimes (Table 1). Groups of yearling sturgeon 1-3 were placed in cages with a stocking density of 70, 132 and 194 pcs/m^2, respectively. These groups of cages were installed in trout ponds with intensive water exchange and water consumption from the deep sections of Lake Kedrozero (water intake depth is 12 meters). This section is characterized by low water temperatures throughout the calendar year and was designed for growing rainbow trout. Two groups of fish 4 and 5 - with a stocking density of 132 and 194 pcs/m^2 were placed for growing in the water area of Lake Onega, in the coastal part, in an area with a shallow depth (3 m) and good conditions for warming up the water in summer.

Table 1. Characteristics of experimental groups and research conditions.

Indicators	Lake Kedrozero, depth 12 m			Lake Onega, depth 3 m	
Thermal constants, degree days	1142			1580	
Group number	1	2	3	4	5
Stocking density, pcs/m^2	70	132	194	132	194
Number of fish, pcs.	157	296	436	296	436

In order to determine the influence of maintenance factors on the condition of fish, we assessed linear-weight indicators at the beginning, in the middle and at the end of the experimental period. For this purpose, we carried out control measurements and weighing of yearlings. Among the morphometric characteristics, we determined the total body length L_0 (body length from the beginning of the snout to the end of the scale covering), head length - from the beginning of the snout to the end of the operculum (L head), maximum body height (H) of yearlings, as well as the Fulton coefficient of condition (K) using the formula:

$$K = [100\times (W/ L^3{}_0), \%) \quad (1)$$

Where, W is the individual live weight of the fish, g

L_0 is the body length from the beginning of the snout to the end of the scale covering, cm

To assess the growth rate of fish, we calculated the absolute (WG), average daily (ADG) and relative (RWG) growth rates using the formulas [8-9]:

$$\textit{Weight gain (g)}\ WG = W_f - W_i \quad (2)$$

$$\textit{Average daily gain, (g/days)}\ ADG = \frac{W_f - W_i}{t} \quad (3)$$

$$\textit{Relative weight gain, (\%)}\ RWG = \frac{W_f - W_i}{W_i} \times 100 \quad (4)$$

where, W_f - final average fish weight, g
W_i - initial average fish weight, g
t, – duration of the period, days

In addition, we also assessed standard fish farming and biological indicators, such as survival rate (% of surviving fish) and fish production (total fish mass yield per unit of rearing area, kg/m^2).

The duration of growing of young sturgeon in the experimental groups was 97 days. During the experimental period, the water temperature was determined daily and the thermal constants in degree-days was calculated (Table 1). During the experimental period, the yearlings were fed with complete balanced feeds for sturgeons.

In data processing, we used analysis of variance [10]. Using one-factor and two-factor analysis of variance, we determined the influence of stocking density and the number of degree days on the morphometric characteristics and weight of sturgeon yearlings. We performed statistical processing of the results in Microsoft Excel.

3 Results

In order to study the characteristics of growing young Siberian sturgeon at different values of stocking density and water temperature, we analysed the linear-weight indicators of fish, as well as the main results of growing in 5 experimental groups (Table 2).

Table 2. Results of growing yearlings of Siberian sturgeon.

Indicators	Lake Kedrozero			Lake Onega	
Thermal constants, degree days	1142			1580	
Group number	1	2	3	4	5
Planting density, pcs/m^2	70	132	194	132	194
Number of fish, pcs.	157	297	436	297	436
Weight, g	118.4±7.63	146.4±15.7	150.0±13.29	199.0±6.63	182.7±16.79
Total body length, cm	30.9±0.50	32.8±1.15	33.5±0.98	37.2±0.81	36.1±0.93
K, %	0.40±0.01	0.41±0.03	0.39±0.01	0.39±0.01	0.38±0.01
Average daily gain, g	1.05	1.35	1.39	1.90	1.73
Relative weight gain, %	546.99	700.00	719.67	987.43	898.36
Survival rate, %	93.6	94.3	83.3	92.9	91.3
Fish products, kg/m^2	7.7	18.2	24.2	24.3	32.3

The average weight of 1 fish at the beginning of the study was the same in all groups – 18.3 g. At the end of the research, the largest weight of fish under low temperature conditions (1142 degree-days) was in group 3 – 150.0 g at a stocking density of 194 pcs/m^2 compared to group 1 – 118.4 g ($P \leq 0.05$) at a stocking density of 157 pcs/m^2. When comparing the results of growing in groups 1–3, we should also note a significant increase in fish production. Thus, at a low stocking density (group 1), there was the lowest fish production rate – 7.7 kg/m^2, with a higher stocking density (group 3), the highest fish production rate was 24.2 kg/m^2, or 3 times higher. Consequently, an increase in the stocking density in the studied options contributes to a more intensive growth of sturgeon yearlings, increases fish production and allows more efficient use of rearing areas.

We should note that the average length of 1 individual at the end of the study was greater in group 3 compared to 1 ($P \leq 0.05$). However, the survival rate of fish in group 3 was lower than in groups 1 and 2.

The fish weight was significantly different when kept in groups 2 and 4 at the same stocking density of 132 pcs/m^2, but different temperature conditions. In a cage with a more optimal temperature of 1580 degree-days, the fish weight by the end of rearing made 199 g, which is 36% more than in group 2 ($P \leq 0.01$).

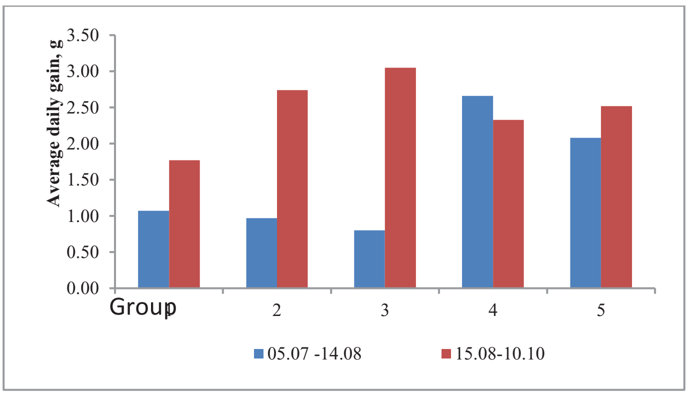
We did not reveal the effect of the two variants of stocking density on the growth rate of sturgeon in groups 4 and 5, which were kept in optimal temperature conditions. There were no reliable differences in weight, length and condition factor of fish. However, the linear-weight indicators of fish in these groups are quite high. The increase in the weight of yearlings at the end of the study compared to the beginning of cultivation was more than 10 times, which indicates favourable rearing conditions. The increase in stocking density did not have a negative effect on the results of cultivation and contributed to an increase in fish production from 24.3 to 32.3 kg/m^2, i.e. a more efficient use of production areas.

We noted the highest average daily gain of fish and relative weight gain in group 4 with a more optimal temperature of 1580 degree-days and with a stocking density of 132 pcs/m^2 compared to other groups. We should note that the growth energy of yearlings was high during the study period. The relative weight gain varied in all groups from 546.99 to 987.43%.

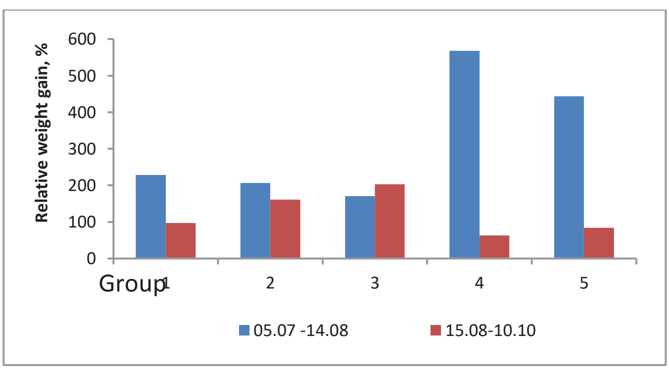
The dynamics of the growth rate of yearlings of Siberian sturgeon by rearing periods is presented in Fig. 1. The average daily gain was higher in all fish groups from 15.08 to

10.10 than in the period from 05.07 to 14.08, except for group 4, where we noted a slight decrease in the indicator from 2.66 to 2.33 g. We found the greatest increase in the average daily gain in group 3 - from 0.80 g in the first period to 3.05 g in the second rearing period.

The relative weight gain rate in this group also increased in the second period from 170 to 203%. The acceleration of the growth rate in this case can probably be explained by the adaptation of the fish to the growing conditions (water temperature, stocking density, behaviour of individuals in the group, availability of food) and the manifestation of good production qualities.



A



B

Fig. 1. Dynamics of average daily (A) and relative weight gain (B) of Siberian sturgeon by rearing periods.

We noted a decrease in the relative weight gain in the second period of cultivation in other groups, compared to the first period. However, the highest relative weight gain for the entire study period was in cages 4 and 5 with a higher amount of heat - 987.43 and 898.36%, which corresponds to the results of many studies indicating intensive growth of sturgeon with a change in water temperature in the range of optimal values. In this case the authors of the studies most often note rapid somatic growth and an increase in muscle mass of sturgeon with an increase in water temperature [11-13]. In some cases, with a decrease in water temperature during cultivation, growth remains quite intensive, but is compensated by changes in the lipid composition of muscle tissue [8, 14].

Along with determining the main fish-breeding indices, including growth rate, we carried out a morphometric assessment of sturgeon fingerlings in the studied groups. We noted that changes in these characteristics (condition factor, constitution, body proportions) indicate the state of populations and provide information on changes in the living conditions of individuals in groups. Variability of morphometric indices is an important feature and is often used both for assessing wild fish populations and for commercial aquaculture purposes, including in the selection assessment of individuals. The data on the assessment of the studied groups of Siberian sturgeon are presented in Table 3.

Table 3. Morphometric characteristics of yearlings of Siberian sturgeon in the middle of the rearing period.

Indicators	Lake Kedrozero			Lake Onega	
Thermal constants, degree days	1142			1580	
Group number	1	2	3	4	5
Stocking density, pcs/m^2	70	132	194	132	194
L_0, см	25.43±1.17	24.86±1.18	24.55±0.90	30.80±0.63	29.92±0.80
L head., cm	6.07±0.32	5.64±0.28	5.70±0.21	12.90±0.52	12.96±0.76
W, g	60.10±8.70	56.14±8.61	49.50±6.25	118.00 ± 14.91	99.42±11.93
H, cm	9.79±0.39	9.43±0.68	8.75±0.47	12.00±1.22	11.94±0.63
K, %	0.35 ±0.01	0.34±0.01	0.32±0.01	0.40±0.04	0.35±0.02

Note: L_0 – total body length, L head – head length, W – weight, g, H – maximum body height, K – fatness coefficient.

The values of the total body length, head length, and maximum body height of fish were significantly greater in groups 4 and 5 than in 1, 2, and 3. Thus, at the same stocking density but different water temperatures, the total body length in group 2 was 24.86 g while in group 4 it made 30.8 g ($P \leq 0.001$). In cages with a more optimal temperature of 1580 degree-days, the morphometric parameters of fish were higher than at a temperature of 1142 degree-days. This is natural, since these groups showed higher average daily, absolute, and relative gains and, as a consequence, greater live weight and an increase in morphometric characteristics. The results of the study of the effect of water temperature on growth are confirmed by the studies of many authors [11, 14, 15].

We used a single-factor analysis of variance to determine the degree of influence of stocking density on the total body length and weight of yearlings. The strength of this factor's influence was low and insignificant. We should note that the share of the influence of stocking density on the total body length (13.7%) and live weight (12.2%) was higher when yearlings were kept at 1142 degree days than at 1580 degree days - 4.2% and 4.3%, respectively.

Stocking density did not have a significant effect on the morphometric characteristics of yearlings - L_0, L_{head}, H and weight, determined in the middle of the growing period. The share of the effect of stocking density on these characteristics was low and insignificant, according to the conducted one-way analysis of variance. Thus, the share of the effect of stocking density on L_0 was 1.7%, L_{head} - 6.3%, H - 11.8% and weight - 4.8% ($P \geq 0.05$).

Fish mass and morphometric features are quantitative characteristics that strongly depend on paratypic factors and their combined effect.

Using a two-factor analysis of variance, we determined the share of the influence of degree-days (factor A), stocking density (factor B) and their combined effect (AB) on the variability of the characteristics of total body length and weight of sturgeon yearlings. Factor A - degree-days was presented in two gradations: A_1 - 1142, A_2 - 1580 degree-days. Factor B - stocking density was tested in two gradations - B_1 - minimum, B_2 - maximum stocking density (Table 4).

Table 4. Results of two-factor analysis of variance of the characteristics of weight and total body length of sturgeon yearlings depending on degree-days and stocking density at the end of the rearing period.

Indicators	A	B	AB	x	z	y
weight						
C_i	32092,2	585,2	5736,0	38413,5	50390,5	88804,0
η^2	0,361***	0,007	0,065*	0,433***	0,567	1
ν_i	1	1	1	3	36	39
$\sigma^2{}_i$	32092,23	585,23	5736,03	12804,49	1399,74	–
F_i	22,9	0,4	4,1	9,2	–	–
total body length						
C	198,0	5,6	34,2	237,9	245,9	483,8
η^2	0,409***	0,012	0,071*	0,492***	0,508	1
ν_i	1	1	1	3	36	39
$\sigma^2{}_i$	198,03	5,63	34,22	79,29	6,83	–
F_i	29,0	0,8	5,0	11,6	–	–

Note: here and below – C_i – variances: C_x – factorial; C_z – residual; C_y – total; η^2 – share of influence of organized ($\eta^2{}_x$) and random ($\eta^2{}_z$) factors; ν_i – number of degrees of freedom; $\sigma^2{}_i$ – variances; F_i – Fisher's test of validity; * – P≤0.05, ** – P≤0.01, ***P≤0.001.

The share of the influence of organized (that were taken into account) factors on the weight of yearlings was 43.3% (P≤0.001). We found low but reliable influence of the interaction of degree-days and stocking density factors on the weight of yearlings – η^2=6.5% (P≤0.05). Degree-days had the greatest influence on the weight – 36.1% (P≤0.001). We did not find any influence of stocking density (η^2=0.7%) on the weight of yearlings as a separate factor.

The variability of the total body length of yearlings was influenced by the total effect of the studied factors – 49.2% (P≤0.001) and their interaction – 7.1% (P≤0.05). The effect of degree-days on the total body length was highly reliable – 40.9% (P≤0.001). At the minimum and maximum stocking, the body length of yearlings at 1580 degree-days was greater than at 1142.

Thus, the number of degree-days, the total effect of the factors taken into account, and the combined effect of degree-days and the stocking density of yearlings had a significant effect on the mass and total body length. Stocking density does not significantly affect these characteristics as a separate factor, but this factor has a force of action at a certain gradation of the number of degree-days.

In our work we studied the influence of degree-days (factor A) and stocking density (factor B), as well as their combined effect (AB) on the variability of morphometric characteristics of sturgeon yearlings (Table 5). (Graduations of factor A: A_1 – 1142, A_2 – 1580 degree-days. For factor B: B_1 – minimum stocking density, B_2 – maximum).

Table 5. Results of two-factor analysis of variance of morphometric characteristics and weight of yearling sturgeon depending on the number of degree-days and stocking density in the middle of the study period.

Indicators	A	B	AB	x	z	y
total body length						
C_i	280.2	7.5	0.0	287.7	250.5	538.2
η^2	0.521***	0.014	0.000	0.535***	0.465	1
ν_i	1	1	1	3	35	38

$\sigma^2{}_i$	280.19	7.54	0.00006	95.91	7.16	–
F_i	39.2	1.1	0.0	13.4	–	–
head length						
C_i	473.4	0.3	0.4	474.1	106.8	580.8
η^2	0.815***	0.001	0.0006	0.816***	0.184	1
ν_i	1	1	1	3	34	37
$\sigma^2{}_i$	473.43	0.30	0.35	158.03	3.14	–
F_i	150.8	0.1	0.1	50.3	–	–
maximum body height						
C_i	57.9	2.9	2.3	63.2	76.5	139.7
η^2	0.415***	0.021	0.017	0.452**	0.548	1
ν_i	1	1	1	3	25	28
$\sigma^2{}_i$	57.93	2.89	2.33	21.05	3.06	
F_i	18.9	0.9	0.8	6.9		
weight						
C_i	28077.2	2064.8	152.4	30294.4	42318.3	72612.7
η^2	0.387***	0.028	0.002	0.417***	0.583	1
ν_i	1	1	1	3	35	38
$\sigma^2{}_i$	28077.21	2064.77	152.41	10098.13	1209.09	
F_i	23.2	1.7	0.1	8.4		

We revealed a reliable and fairly large share of the influence of organized (that were taken into account) factors on the indicators of morphometric characteristics and body weight of yearlings – 41.7–81.6%. This means that the number of degree-days and the density of fish stocking determined to a significant extent the diversity of morphometric characteristics and weight of fish observed in the study.

The share of the effect of degree-days on the morphometric characteristics and weight of fish was also reliable and significant – 38.7–81.5% ($P \leq 0.001$). The share of the effect of degree-days on the total body length was 52.1% ($P \leq 0.001$), on the head length 81.5% ($P \leq 0.001$), on the maximum body height 41.5% ($P \leq 0.001$), weight – 38.7% ($P \leq 0.001$).

A certain regularity can be noted by comparing the obtained partial averages: we observed higher indices of morphometric features when growing yearlings at 1580 degree-days, lower ones – at 1142 degree-days. A higher number of degree-days increased the indices of morphometric features at different stocking densities

4 Conclusion

The influence of different stocking density as a separate factor and the interaction of degree-day gradations and stocking density on the indices of variability of morphometric characteristics was very small and unreliable, i.e. we found no dependence of the influence of each factor on the gradation of another factor. The low share of the influence of the stocking density of yearlings on the indices of morphometric characteristics can be explained by the high variability of these characteristics, which is typical for Siberian sturgeon, which has a large number of evolutionary adaptations and high ecological plasticity [16], as well as the correlation of exterior indices with other factors.

Thus, the study revealed a reliable influence of degree-days and the combined effect of degree-days and stocking density on the variability of morphometric characteristics and weight of yearling sturgeon.

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