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Original Article

Effect of different oxygen concentrations and stocking density on the growth and development of *Acipenser ruthenus* in a recirculating aquaculture system

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Abstract

This article presents the results of a 30-day study investigating the impact of varying oxygen concentrations and stocking densities on the growth and development of sterlet (*Acipenser ruthenus*) in a recirculating aquaculture system (RAS). As a result, it was established that a stocking density of 40 kg/m³ provides the best indicators of mass growth (relative increase of 55.6%, specific growth rate of 1.47%, absolute increase of 42.9 g, average daily increase of 1.43 g/day), which makes it optimal. High density (80 kg/m³) reduces growth by 17-21% compared to 40 kg/m³, which can be very important for production. Productivity is increased by density: maximum at 80 kg/m³ (114.4 kg/m³ and 91.5 kg/m²), then 60 kg/m³ (89.5 kg/m³ and 71.6 kg/m²) and minimum at 40 kg/m³ (61.8 kg/m³ and 49.4 kg/m²). The feed factor is minimal at 40 kg/m³ (1.23 units) and is increased to 1.29 units at 60 and 80 kg/m³, indicating a decrease in feed efficiency at higher densities. High stocking density (80 kg/m³) increases biomass gain and productivity (114.4 kg/m³, 91.5 kg/m²), but decreases individual gain and feed efficiency. Thus, the results of the studies showed that the optimal conditions for the normal growth and development of sterlet in recirculating aquaculture system (RAS) installations include the following parameters: a dissolved oxygen content of 8-10 mg/L and a stocking density of 40-60 kg/m³.

Keywords: Sterlet, *Acipenser ruthenus,* Dissolved oxygen, Stocking density, RAS

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Introduction

Aquaculture plays a pivotal role in the conservation of sturgeon species, offsetting anthropogenic pressure on natural populations through sustainable reproduction (Dudu and Georgescu, 2024; Chandra and Fopp-Bayat, 2021; Boscari et al., 2017). As the fastest-growing sector in global agriculture (Obirikorang et al., 2024), it has achieved significant technological advances in sturgeon farming (Tavakoli et al., 2021). Modern methods, particularly recirculating aquaculture systems (RAS), enable optimization of all environmental parameters, thereby increasing productivity and minimizing impacts on natural water bodies (Lobanov et al., 2021; Artem et al., 2023). According to available data, 21% of 2,329 commercial sturgeon farms in 45 countries are equipped with RAS (Bronzi et al., 2019).

The sterlet (*Acipenser ruthenus*) is one of the most promising species for RAS due to its early sexual maturity, high growth rate, short reproductive cycle, adaptability, and valuable consumer qualities (Ljubobratović et al., 2022; Linhart et al., 2016). Successful sterlet rearing in closed systems requires strict control of environmental (temperature, dissolved oxygen) and technological (stocking density) parameters, especially during early ontogenetic stages (Ginayatov et al., 2024; Kurbanov et al., 2024).

Dissolved oxygen is a critical factor for fish metabolism and growth (Bulbul Ali and Mishra, 2022). Hypoxia induces stress, competition for oxygen, and physiological disturbances in sterlet (Kurbanov et al., 2024). Stocking density, in turn, directly affects feed and oxygen access, stress levels (cortisol, thyroid hormones), feed efficiency, and final body weight (Long et al., 2019; Li et al., 2012; Ren et al., 2017; Rafatnezhad et al., 2008). Moreover, the interaction of these factors in RAS remains poorly understood: high density sharply increases oxygen demand, exacerbating the risk of hypoxia and growth suppression.

Despite extensive data on individual parameters, the combined effect of varying dissolved oxygen concentrations and stocking densities on sterlet growth, physiology, and survival in RAS has not been systematically investigated. Optimizing these factors using advanced monitoring and environmental control technologies will enhance farming efficiency and reduce production risks.

The aim of this study was to quantify the interactive effects of dissolved oxygen concentrations (6–8, 8–10, and 10–12 mg/L) and stocking densities (40, 60, and 80 kg/m³) on growth performance (specific growth rate, biomass gain, feed conversion ratio), physiological status, and survival of juvenile sterlet (*Acipenser ruthenus*) in a recirculating aquaculture system (RAS), addressing the underexplored combined impact of these factors on early-stage development in closed-loop production systems.

Materials and Methods

Experimental fish

The object of this study is the sterlet (*Acipenser ruthenus Linnaeus*, 1758), a species of fish that inhabits freshwater and is placed within the sturgeon family. The research was carried out on juvenile sterlets. The experiment involved 5,510 specimens, with an average weight of 71.9-77.8 g and an average body length of 27.6-28.3 cm. The experimental duration was 30 days.

Experimental conditions

The research was carried out using polypropylene pools. Each pool has a working volume of 0.64 m³ and the following dimensions: 3.2 m x 0.5 m x 0.5 m (water depth: 0.4 m) RAS (Figure 1). The RAS includes the following: 24 tray-type fish-breeding pools, a cone oxygenator with a capacity of 60 m³/hour, a mechanical drum filter with a capacity of 180 m³/hour, three pumps with a capacity of 40 m³/hour, a sterilizer, a blower, a 4.8 m³ floating load biological filter, an oxygen station with a capacity of 50 L/min. Oxygen supply rates were regulated using rotameters. The recirculating aquaculture system (RAS) was housed in an indoor facility with a total area of 400 m², where water temperature was maintained within a range of 17.5–22.8 °C using a combined heating and air-conditioning system. Daily water replacement accounted for 12–18% of the total system volume, while the water exchange rate was maintained at 2.0–2.5 turnovers per hour.

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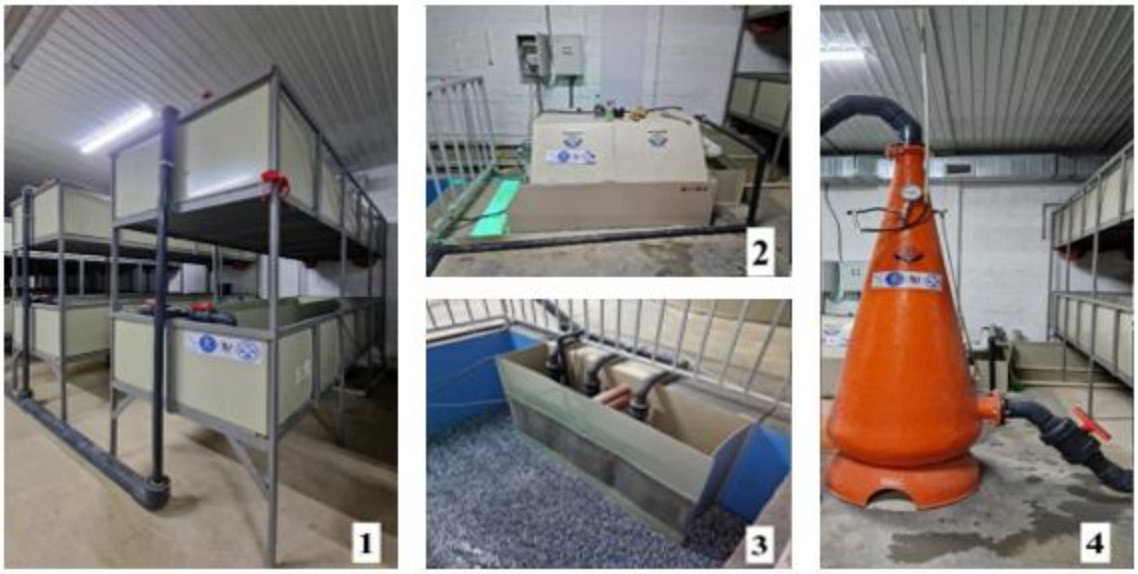

Figure-1. Closed water supply installation: 1 – tray-type pools; 2 – mechanical drum filter with bactericidal treatment with ultraviolet light; 3 – biological filter with pumps; 4 – oxygen cone.

Water quality analysis

The analysis of hydrochemical indicators (Table 1) was carried out in the environmental analytical laboratory of the environment of the International Taraz University named after Sh. Murtaza. Water characteristics were determined in accordance with the following regulatory documents: sulfates – GOST 26449.2–85p.15, chlorides – GOST 26449.1–85p.9.p 9.1, carbonates – GOST 26449.1–85p.7.p 7.2, calcium – GOST 26449.1–85p. 11 p11.1, nitrites – GOST 26449.2–85p.11, magnesium – GOST 26449.1–85p.12. p12.1, nitrates – GOST 26449.2–85p.12, ammonia and ammonium ions – GOST 33045–2014 p.5, phosphates – GOST 26449.1–85p.14 p14.2 (Gosstandart, 1987). Sampling during the experiment was carried out twice a week.

Table-1. Hydrochemical water parameters in the RAS basins during the experiment.

Indicators	Meaning
rN	7.1 - 8.0
Suspended substances, mg/l	2.0 - 4.9
Turbidity, mg/l	0.4 - 0.6
Nitrates (NO_3), mg/l	11.3 - 13.2
Nitrites (NO_2), mg/l	0.02 - 0.03
Oxidability is permanganate, mg/O2/l	6.0 - 7.0
Ammonium nitrogen, mg/l	1.2 - 1.3
Phosphates, mg/l	0.07 - 0.08
COD (dichromate oxidability), mg/O2 /l	23.3 - 27.4

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Characteristics of a fresh water source from an artesian well: nutrients – rN – 7.5, NH_4 – 0.002 mg/l, NO_2 – 0.002 mg/l, NO_3 – 0.01 mg/l, R.O.$_4$ – 0.19 mg/l, C.r (VI) – 0.001 mg/l, Su – 0.01 mg/l, Fe – 0.006 mg/l; ionic composition – CO3 – none, HCO3 – 247.2 mg/l, Cl – 48.3 mg/l, SO4 – 32.0 mg/l, Ca – 116.1 mg/l, Mg – 12.0 mg/l, Ca+Mg – 6.81 mg/l, Na+K – 18.2 mg/l.

Feeding of the studied fish was carried out with compound feed SteCoSUPREME–15 (total energy 21 MJ/kg, protein – 46.0%, fat – 15.0%) granule size 3 mm, according to methods developed in fish farming and recommendations of the feed manufacturer (Shcherbina and Gamygin, 2006). The daily feeding rate was 2%. Every 10 days, daily feeding standards were adjusted taking into account changes in biomass in the experimental groups.

During the experiment, the main hydrochemical indicators were within fish farming standards (Chebanov and Galich, 2013). These reference standards were used to define the experimental ranges of dissolved oxygen concentration and stocking density. The dissolved oxygen concentration was increased above commonly accepted baseline levels in order to evaluate the potential for improving rearing efficiency through supplemental oxygenation. The maximum oxygen level was selected based on concentrations approaching the threshold associated with an increased risk of gas bubble disease, while the intermediate level was chosen between the baseline and the maximum values. Stocking density was similarly increased above conventional levels to assess the potential for enhancing volumetric productivity of rearing tanks while maintaining individual growth performance. The maximum stocking density was selected based on regulatory and operational guidelines for short-term holding of fish at high biomass loads, and the intermediate density was defined as the midpoint between the baseline and maximum values.

Fish-water indicators were determined according to the calculation formulas generally accepted in fish farming (Shcherbina and Gamygin, 2006). Relative increase ΔM and specific growth rate (*Cw*) calculated using formulas (22): $\Delta M = (Mt–M_0)/M_0*100\%$; $CW = (lnMt – lnM_0)/t*100\%$, where M_0, Mt – mean at beginning and end of period, respective.

Mass of fish measured using a laboratory scale Mass – K VK– 300.1 (discreteness 0.01 g) to the nearest 0.1 g. The length was measured from the nose to the end of the caudal fin to within 1 mm. The temperature and concentration of oxygen in the water were checked with oximeter DO8403, pH–meter HI 98121.

The experiment was carried out in duplicate, and the results of each group were combined. For statistical analysis, random samples (n = 50) were taken from each replicate, resulting in a final sample size of 100 individuals per experimental group.

Experimental design and treatments

Two separate experiments were conducted to evaluate the effects of dissolved oxygen concentration and stocking density on juvenile sterlet growth and development.

For the dissolved oxygen experiment, three groups were established in duplicate (n = 6 pools total):

– Group 1: 6–8 mg/L;
– Group 2: 8–10 mg/L;
– Group 3: 10–12 mg/L.

Two hundred juveniles (initial mean weight 71.9–72.7 g) were randomly allocated to each pool. Dissolved oxygen was monitored twice daily (morning and evening) using oximeters. To achieve higher oxygen levels in Groups 2 and 3, an additional water supply line equipped with a cone oxygenator (capacity 15 m³/h) was installed. Flow rates from the main and additional lines were adjusted to ensure equivalent water exchange (two full volumes per day) across all pools, maintaining uniform conditions except for oxygen concentration. Water temperature ranged from 18.0 to 22.2 °C throughout the experiment.

For the stocking density experiment, three groups were established in duplicate (n = 6 pools total):

– Control (Group 1): 40 kg/m³;
– Treatment 2: 60 kg/m³;
– Treatment 3: 80 kg/m³.

Juveniles were randomly distributed to achieve the target densities. Water exchange rate was maintained at 2.5 volumes per day, ensuring dissolved oxygen remained within 6.2–8.1 mg/L across all groups. Water temperature ranged from 18.0 to 22.2 °C.

All treatments were conducted using tray-type polypropylene pools within the same RAS facility.

Statistical analysis

Data were analyzed using standard statistical methods (Lakin, 1990). Assumptions of parametric tests were verified using Levene's test for homogeneity of variances and the Shapiro-Wilk test for normality. One-way analysis of variance (ANOVA) was

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employed to detect overall differences among groups, followed by pairwise comparisons using Student's t-test. Differences were considered significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

Descriptive statistics included the mean ($\bar{x}$), standard deviation (σ), coefficient of variation (CV), median, and 25th and 75th percentiles. All calculations and graphical presentations were performed using Microsoft Excel 2021 and Statistica 12.

Results

Effect of different oxygen concentrations for growth and development sterlet blackling

At the beginning of the experiment under different oxygen conditions of the aquatic environment in RAS basins there are no statistically significant differences between average masses and lengths in the experimental groups.

Levene's test for equality of variances ($p>0.05$) throughout the experiment allows the use of parametric tests (ANOVA and Student's t-test). At the end of the experiment, there are significant differences in mass between the groups as a whole ($p<0.001$ (ANOVA)) (Table 2). There are no statistically significant differences between the mean lengths at the beginning and end of the experiment in the experimental groups ($p> 0.05$).

Table-2. Weight and length of sterlet under different oxygen conditions of the aquatic environment in RAS pools.

Oxygen concentration	6–8 mg/l	8–10 mg/l	10–12 mg/l
Mass (n=100)			
Period		$\bar{x} \pm \sigma$, g Min – max, g CV, %	
Beginning of the experience	72.7 ± 7.5 48.4 - 92.5 10.3	71.9 ± 7.2 54.6 - 88.8 10.1	72.3 ± 7.7 53.6 - 89.9 10.6
End of experience	110.3 ± 13.3 84.3 - 141.8 12.1	118.1 ± 11.1* 87.4 - 141.9 9.4	116.7 ± 11.8* 87.1 - 151.1 10.1
Length (n=100)			
Period		$\bar{x} \pm \sigma$, cm Min – max, see CV, %	
Beginning of the experience	27.5 ± 1.4 23.0 - 31.3 5.1	27.8 ± 1.5 24.3 - 31.2 5.3	28.0 ± 1.4 24.6 - 31.3 5.1
End of experience	32. 3 ± 2.0 28.5 - 36.9 6.1	32.4 ± 1.9 27.2 - 36.4 5.8	32.2 ± 1.8 27.5 - 37.6 5.7

Note: 1. normality of distribution (Shapiro-Wilk test): p-values > 0.05; 2. when compared with the experimental group with oxygen concentration 6-8 mg/l (student's t-test): * – $p \leq 0.001$; * – $p \leq 0.01$;** – $p \leq 0.05$.

The experiment was concluded with an oxygen regime of 6-8 mg/l, at which point a significant difference was observed in the average weight of 110.3 g ($p<0.001$). This result was in contrast to the content of fish in water with a higher oxygen concentration of 8–10 mg/l and 10–12 mg/l, which had an average weight of 118.1 g (a difference of 7.8 g, or 7.1%) and 116.7 g (a difference of 6.4 g, or 5.9%), respectively. These results were found to be indistinguishable from each other. The means and medians are not identical but are very close (difference <1.6 g, <1.4%) (see Figure 2).

The mean length values are almost identical (range 32.2-32.4 cm) (ANOVA $p> 0.89$), indicating no significant variations. The coefficient of variation is

low in all groups. It is less than 7%. This shows low relative variability of the data. It was found that the means and medians are not identical, but very close (difference <0.2 cm, <0.5%).

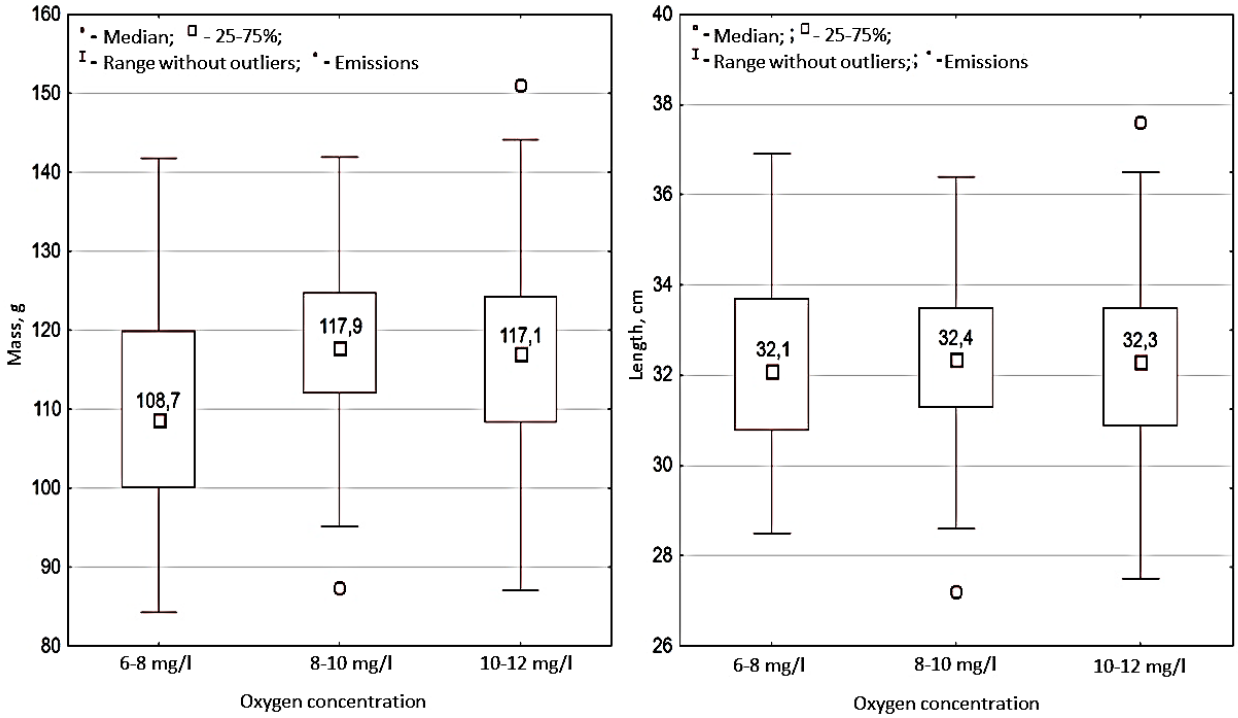

Figure-2. Mass and length of sterlet under different oxygen conditions in the water environment in recirculating aquaculture systems at the end of the experiment.

The masses and lengths of the experimental group with 6-8 mg/l oxygen are most variable (*CV* 12.1% and 10.1%, respectively) at the end of the experiment, indicating a greater dispersion of values and the influence of this factor on the individual development of individuals (Figure 3).

In Figure 4, the most pronounced differences were observed between the 6–8 mg/L and 8–10 mg/L oxygen groups, reaching 22.6% for absolute growth increment and 23.2% for average daily growth increment. These substantial disparities underscore the marked enhancement in growth performance associated with elevating dissolved oxygen concentration to the 8–10 mg/L range. In contrast, differences between the 8–10 mg/L and 10–12 mg/L groups were minimal, indicating that the optimal dissolved oxygen concentration for body mass gain in juvenile sterlet likely lies within or near the 8–10 mg/L interval under the conditions tested.

As illustrated in Figure 5, the most substantial differences were observed between the 6–8 mg/L and 8–10 mg/L oxygen groups, amounting to 24.0% for relative growth increment and 18.7% for specific growth rate. These marked disparities highlight the significant enhancement in growth performance achieved by increasing dissolved oxygen concentration into the 8–10 mg/L range. Conversely, differences between the 8–10 mg/L and 10–12 mg/L groups were negligible, suggesting comparable efficacy under these conditions. This pattern aligns closely with prior observations on body mass gain, reinforcing that a dissolved oxygen concentration of 8–10 mg/L represents the optimum for promoting body weight accrual in juvenile sterlet within the tested RAS framework.

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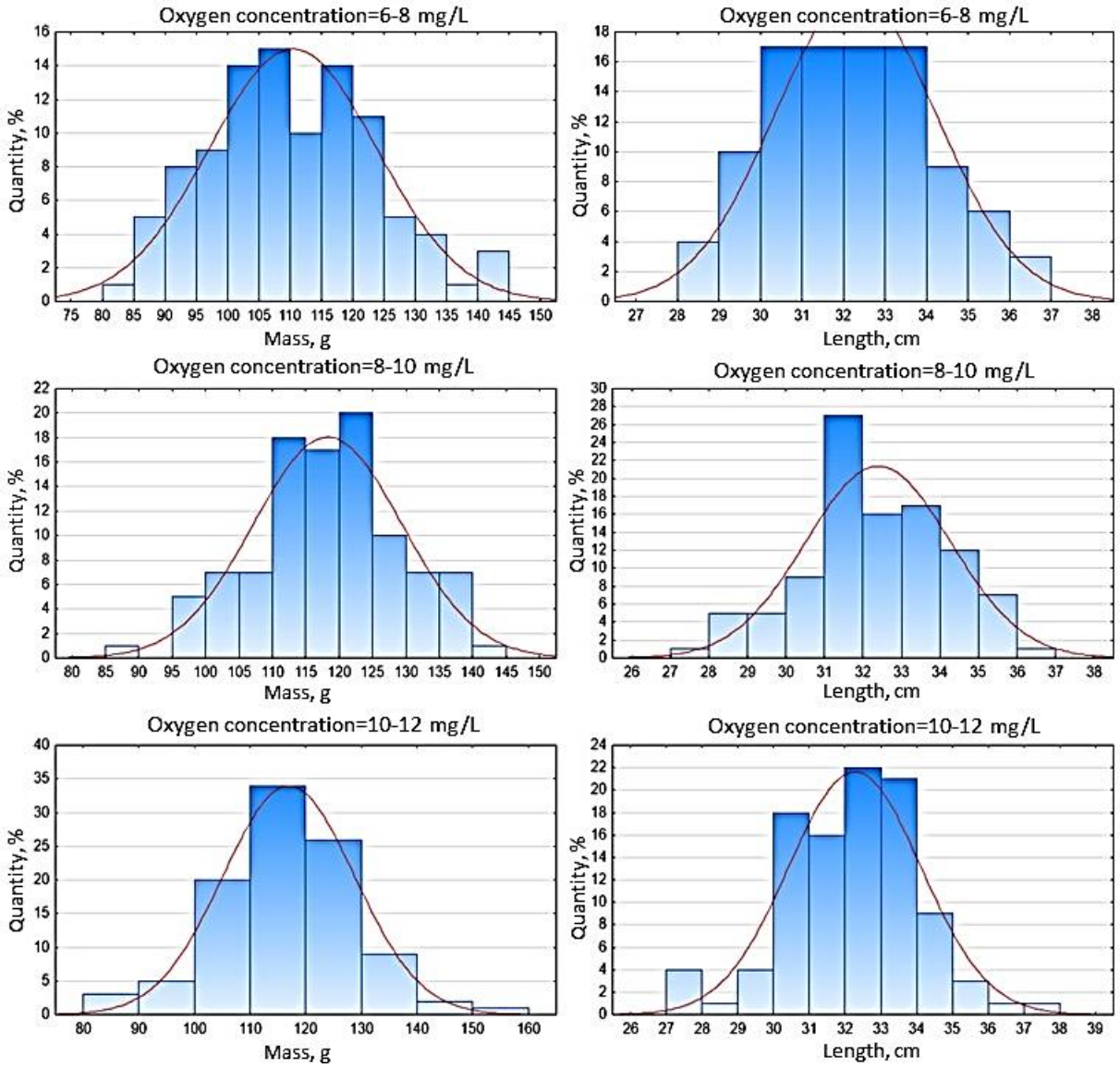

Figure-3. Variational series of mass and length sterlets under different oxygen conditions of the aquatic environment in RAS pools at the end of the experiment.

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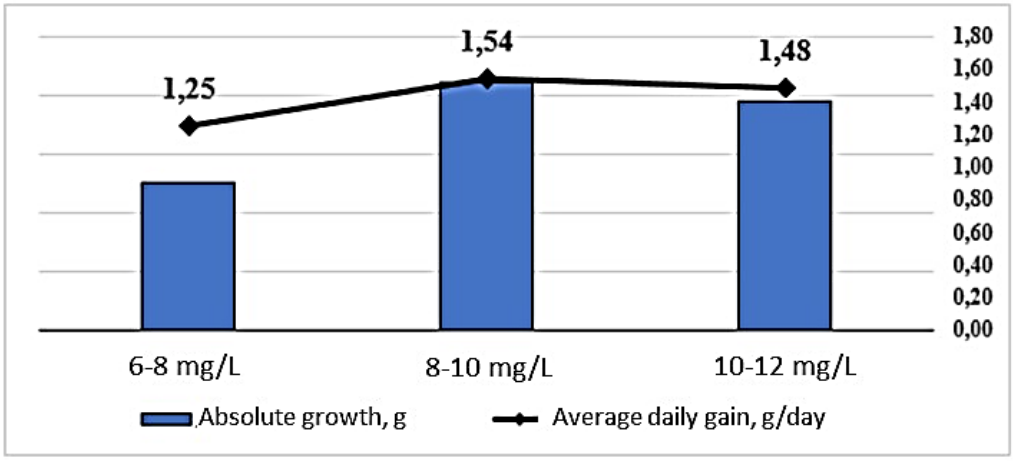

Figure-4. Absolute measures of mass growth dynamics sterlets under different oxygen conditions of the aquatic environment in RAS pools.

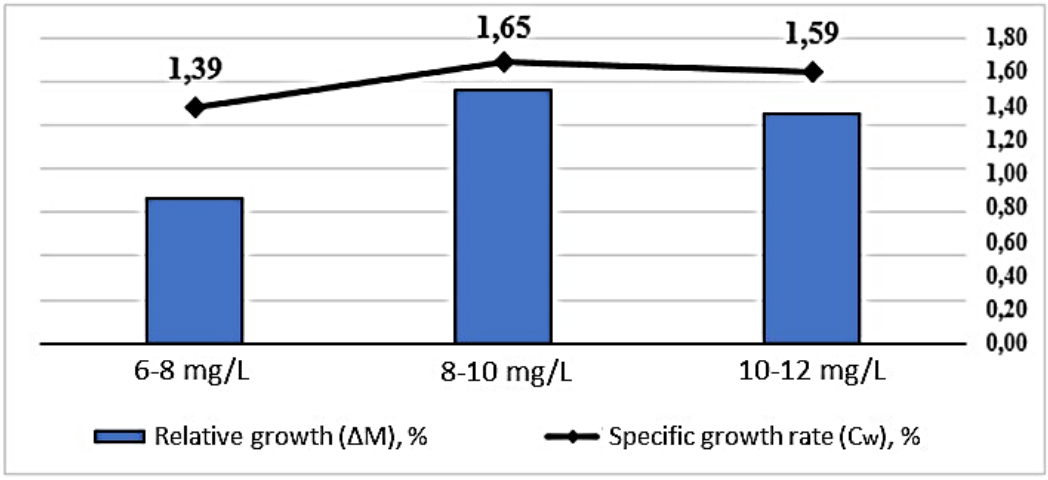

Figure-5. Relative measures of mass growth dynamics sterlets under different oxygen conditions of the aquatic environment in RAS pools.

The feed factor (the amount of feed required to obtain 1 kg of weight gain) is minimal and equal to 1.22 units at 8-10 mg/l, indicating the highest feed efficiency (Figure 6). Productivity, calculated both per unit volume and per unit bottom area of the production tanks, reached its maximum at 8–10 mg/L dissolved oxygen. This finding aligns with the previously observed peak in body mass growth under the same oxygen regime. The most pronounced differences were evident between the 6–8 mg/L and 8–10 mg/L groups, amounting to 6.2–6.3% for productivity metrics and 3.3% for the feed conversion ratio, underscoring the substantial improvements in production efficiency and feed utilization associated with the intermediate oxygen concentration. In contrast, differences between the 8–10 mg/L and 10–12 mg/L groups were minimal (0.7–2.4%), indicating comparable performance under these conditions.

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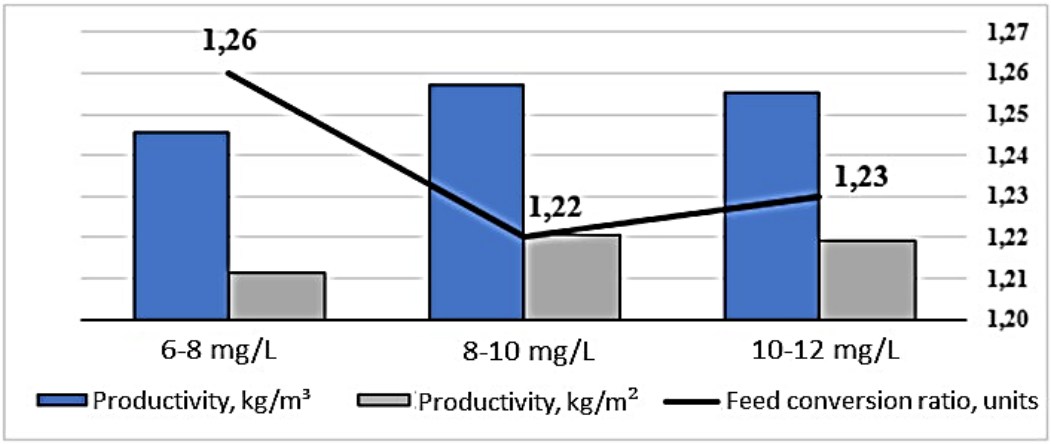

Figure-6. Indicators of relative productivity of sterlet under different oxygen conditions of the aquatic environment in RAS pools.

Survival rate remained consistently high (>98%) across all oxygen regimes, with only a minor decrease observed in the 8–10 mg/L group (Table 3). These negligible differences confirm robust survival irrespective of dissolved oxygen concentration within the tested range.

Initial biomass showed minimal variation among groups (0.3–1.0% difference), verifying comparable starting conditions. The highest biomass gains were recorded at 8–10 mg/L dissolved oxygen, with the lowest at 6–8 mg/L. This reinforces the superiority of the 8–10 mg/L regime for individual growth, as evidenced by corresponding adjustments in daily feeding rates and elevated feed intake. The most pronounced differences occurred between the 6–8 mg/L and 8–10 mg/L groups, reaching 18.3% for biomass increment and 15.7% for feed consumption. Higher feed intake at 8–10 mg/L directly contributed to greater biomass accrual, explaining the lower feed conversion ratio in this group, where enhanced growth efficiently compensated for increased consumption.

Stocking density was nearly identical across treatments, confirming tightly controlled experimental conditions. Consequently, observed variations in performance can be attributed to differences in dissolved oxygen concentration rather than stocking density.

Table-3. Technological indicators of sterlet cultivation under different oxygen conditions of the aquatic environment in RAS pools.

Oxygen concentration		6-8 mg/l	8-10 mg/l	10-12 mg/l
Quantity, copies.	Beginning of the experience	400	400	400
	End of experience	396	395	396
Survival, %		99.0	98.8	99.0
Water volume, m			1.28	
Bottom area, m^2			1.6	
Biomass, kg	Beginning of the experience	29.07	28.77	28.93
	End of experience	43.66	46.64	46.22
Biomass gain, kg		14.59	17.86	17.29
Feed consumption, kg		18.38	21.79	21.26
stocking density	kg/m^3	22.7	22.5	22.6
	kg/m^2	18.2	18.0	18.1
Growing period, days.		30	30	30

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Influence of different stocking densities for growth and development sterlet blackling

At the beginning of the experiment with different stocking densities in RAS pools there are no statistically significant differences between average masses and lengths in the experimental groups. At the end of the experiment, there are significant differences in mass between the groups as a whole (p<0.001 (ANOVA)) (Table 4). There are no statistically significant differences between the mean lengths at the beginning and end of the experiment in the experimental groups (p> 0.05).

Table-4. Mass and length of sterlet at different stocking densities in RAS pools.

stocking density	40 kg/m^3	60 kg/m^3	80 kg/m^3
Mass (n=100)			
Period		$\bar{x} \pm \sigma$, cm Min – max, see CV, %	
beginning of the experience	77.3 ± 7.8 55.6 - 94.1 10.1	77.8 ± 8.5 60.6 - 101.8 10.9	76.9 ± 8.1 52.3 - 105.2 10.5
end of experience	120.2 ± 14.5 92.0 - 154.6 12.1	116.6 ± 12.6 81.9 - 143.5 10.8	110.7 ± 13.4* 76.9 - 149.9 12.1
Length (n=100)			
Period		$\bar{x} \pm \sigma$, cm Min – max, see CV, %	
beginning of the experience	28.2 ± 1.4 24.2 - 31.2 5.1	28.3 ± 1.6 25.0 - 32.9 5.7	28.2 ± 1.4 23.9 - 33.2 5.0
end of experience	32.7 ± 2.0 28.9 - 37.3 6.1	32.5 ± 2.1 26.7 - 37.0 6.4	32.2 ± 1.9 27.3 - 38.0 6.0

Note: 1. normality of distribution (Shapiro-Wilk test): p-values > 0.05; 2. when compared with the experimental group with oxygen concentration 6-8 mg/l (student's t-test): * – $p \leq 0.001$; * – $p \leq 0.01$;** – $p \leq 0.05$.

At the end of the experiment, mean values indicated that the group with a stocking density of 40 kg/m³ exhibited the highest performance. A statistically significant difference of 9.5 g (or 8.6%) was observed between the 40 kg/m³ and 80 kg/m³ groups ($p < 0.001$). The 60 kg/m³ group differed from the 80 kg/m³ group by 5.9 g (5.3%; $p < 0.01$), but showed no significant difference from the 40 kg/m³ group ($p > 0.05$). Although means and medians were not identical, they were very close (difference < 1.8 g, < 1.5%) (Figure 7).

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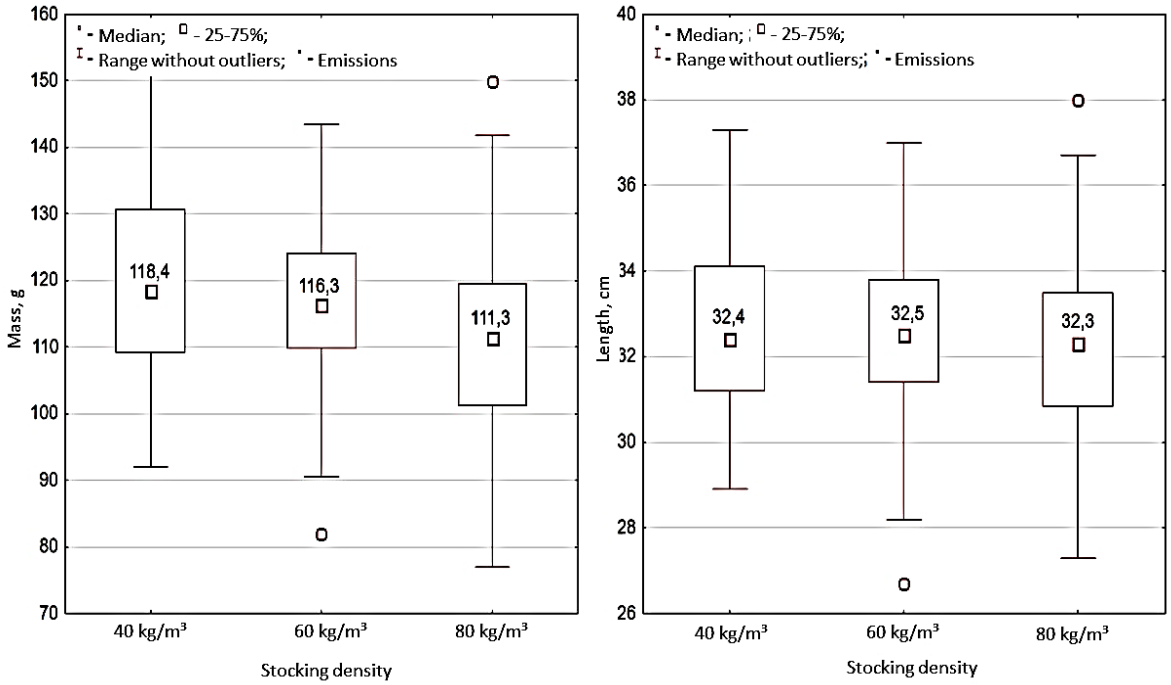

Figure-7. Weight and length of sterlet at different stocking densities in the RAS pools at the end of the run.

The average lengths are close. The range is 32.2-32.7 cm. There is a minimal decrease with increasing stocking density. The results of the analysis of variance (ANOVA) indicate that the effect of stocking density on length is not significant ($p > 0.05$). This is consistent with experimental data on different oxygen concentrations, where length also remains stable. While the means and medians are not identical, they are very close (difference <0.3 cm, <0.8%).

The mean lengths at the beginning and end of the experiment in the experimental groups are not statistically significantly different ($p>0.05$).

The experimental group, which had a stocking density of 40 kg/m3, showed the most variation at the end of the experiment. This suggests that there was greater dispersion of values and that this factor influenced the individual development of the subjects. At the same time, the experimental group with a stocking density of 60 kg/m³ stands out. This is because it has a wide range of lengths. Then there is an experimental group of 80 kg/m³. You can see this in Figure 8.

Absolute and average daily growth increments decreased progressively with increasing stocking density (Figure 9). The most substantial reductions of 21.2% for absolute growth and 21.0% for average daily growth were observed between the 40 kg/m³ and 80 kg/m³ groups. Differences between 40 kg/m³ and 60 kg/m³, as well as between 60 kg/m³ and 80 kg/m³, were moderate but demonstrated a consistent downward trend. These findings indicate a negative impact of high stocking density on individual body weight gain in sterlet.

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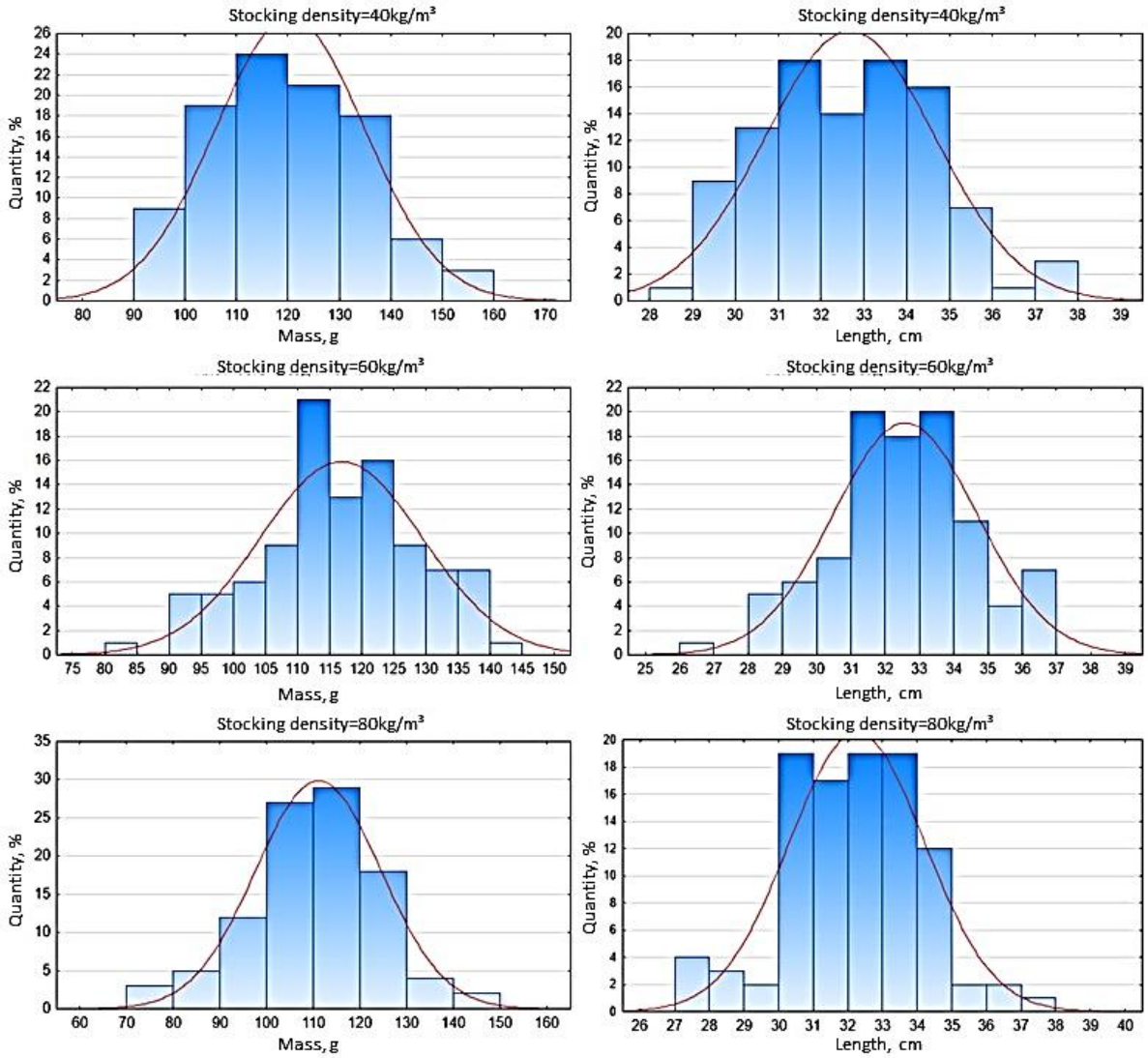

Figure-8. Variational series of mass and length sterlets at different stocking densities in RAS pools at the end of the experiment.

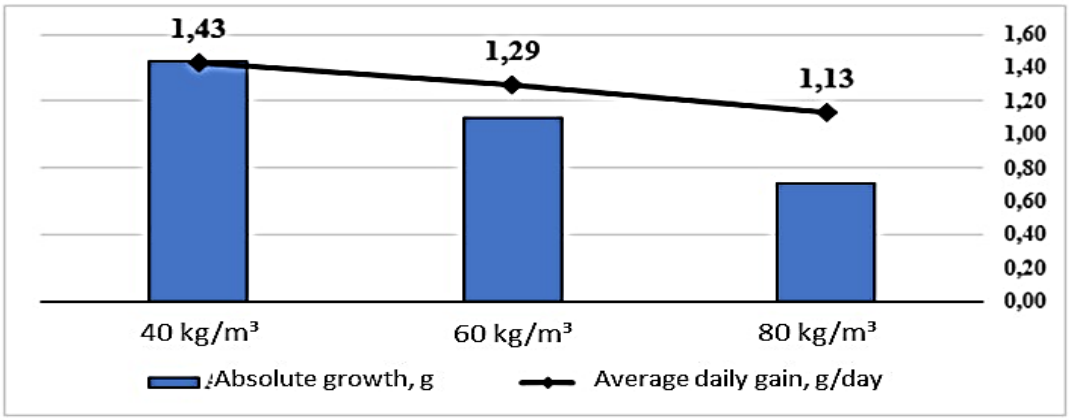

Figure-9. Absolute measures of mass growth dynamics sterlets at different stocking densities in RAS pools.

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Relative gain and specific growth rate of mass decrease with increasing stocking density (Figure 10). The greatest difference is between 40 kg/m³ and 80 kg/m³: 21.0% for relative growth and 17.7% for specific growth rate, highlighting a significant deterioration in growth at high density. The differences between 40 and 60 kg/m³ and between 60 and 80 kg/m³ are moderate, but show a consistent decline. This is consistent with previous mass data (absolute gain of 42.9–33.8 g, average daily gain of 1.43-1.13 g/day), confirming the negative impact of high density on mass growth.

High density (80 kg/m³) reduces growth by 17–21% compared to 40 kg/m³, which can be critical for production purposes.

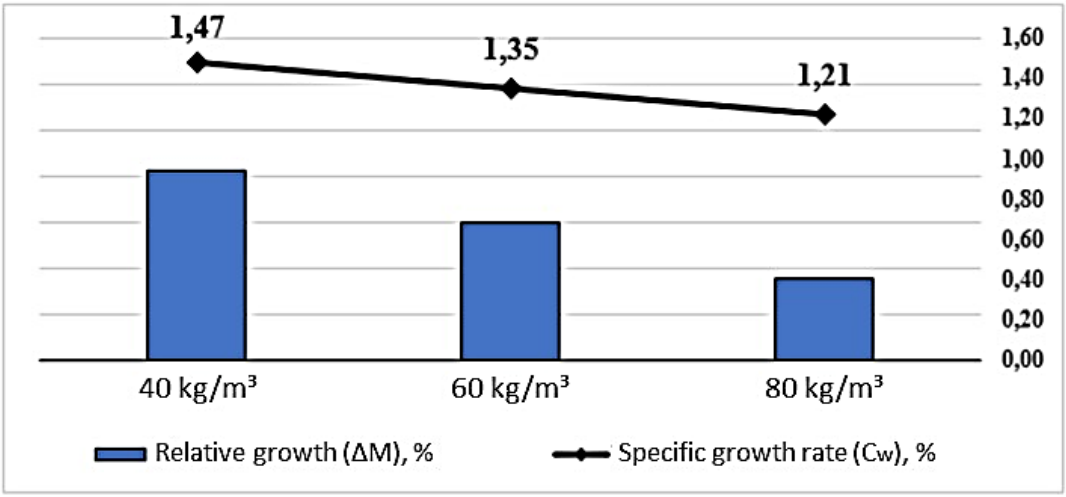

Figure-10. Relative measures of mass growth dynamics sterlets at different stocking densities in RAS pools.

Survival rates were consistently high across all stocking densities (>99.4%), indicating that stocking density within the tested range (40–80 kg/m³) had negligible impact on survival (Table 5).

Biomass gain increased progressively with stocking density, driven primarily by higher numbers of individuals per pool (662–1,330), despite reduced individual growth performance. Correspondingly, total feed consumption rose with density (34.38–56.85 kg), reflecting the greater overall biomass and stocking numbers. The feed conversion ratio ranged from 1.23 to 1.29, with higher values at elevated densities signifying diminished feed efficiency.

High stocking density (80 kg/m³) maximized total biomass gain and productivity but compromised individual growth and feed utilization efficiency. The most marked differences occurred between the 40 kg/m³ and 80 kg/m³ groups, reaching 36.6% for biomass increment and 39.5% for feed intake, highlighting the substantial increase in total biomass production at higher densities. Intermediate differences between 40 kg/m³ and 60 kg/m³ (25.7–29.2%) and between 60 kg/m³ and 80 kg/m³ (14.6%) further confirmed the positive relationship between stocking density and overall biomass accrual.

Table-5. Technological indicators of sterlet cultivation at different stocking densities in RAS pools.

stocking density		**40 kg/m³**	**60 kg/m³**	**80 kg/m³**
Quantity, copies.	beginning of the experience	662	988	1330
	end of experience	658	982	1322
Survival, %		99.4	99.4	99.4
Water volume, m³			1.28	
Bottom area, m²			1.6	

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Biomass, kg	beginning of the experience	51.14	76.87	102.32
	end of experience	79.09	114.50	146.39
Biomass gain, kg		27.95	37.63	44.07
Feed consumption, kg		34.38	48.55	56.85
stocking density	kg/m^3	40.0	60.1	79.9
	kg/m^2	32.0	48.0	63.9
Growing period, days.		30	30	30

Discussion

The present study demonstrates that dissolved oxygen concentrations and stocking density significantly influence the growth performance and feed utilization of juvenile sterlet (*Acipenser ruthenus*) in RAS. Optimal individual growth was achieved at 8–10 mg/L dissolved oxygen and 40 kg/m³ stocking density, while higher densities increased total biomass yield at the expense of feed efficiency and individual weight gain. The superior growth at 8–10 mg/L oxygen, compared to 6–8 mg/L (7.1% higher final weight) and 10–12 mg/L (no significant advantage), aligns with the high oxygen requirements of sturgeons. Hypoxia (6–8 mg/L) likely induced chronic stress, elevating cortisol and reducing metabolic efficiency, as evidenced by higher growth variability (CV = 12.1%). This is consistent with observations in other sturgeons, where hypoxia depresses oxygen consumption and swimming activity by 57–70%, limiting energy allocation to growth (Crocker and Cech, 1997; Bulbul Ali and Mishra, 2022). In contrast, hyperoxic conditions (>10 mg/L) may not further enhance growth in sterlet juveniles, unlike longer-term studies where high DO (11.2 mg/L) improved weight gain over 37 months (Ineno et al., 2018). The absence of length differences across oxygen regimes suggests that hypoxia primarily affects weight accrual via reduced feed intake or assimilation rather than skeletal development.

Stocking density exhibited a clear trade-off: 40 kg/m³ maximized specific growth rate (1.47%) and minimized feed conversion ratio (1.23), while 80 kg/m³ boosted biomass productivity (114.4 kg/m³) but reduced individual growth by 17–21% and impaired feed efficiency (FCR = 1.29). This pattern reflects increased competition for resources and elevated stress (e.g., cortisol-mediated suppression of appetite and immunity), commonly reported in sturgeons (Long et al., 2019; Jia et al., 2022). Comparable findings in Siberian sturgeon larvae showed optimal growth at low densities (30 larvae/L), with high densities (150 larvae/L) inhibiting muscle development (Aidos et al., 2019). For juvenile sterlet, our recommended range (40–60 kg/m³) is higher than larval optima (e.g., 20 larvae/L) (Fazekas et al., 2022) but aligns with juvenile Chinese sturgeon tolerances (Li et al., 2021), reflecting ontogenetic shifts in density tolerance.

The interaction between oxygen and density, though not explicitly tested here, is implied: higher densities amplify oxygen demand, exacerbating hypoxia risks in RAS. This underscores the need for robust oxygenation in intensive systems.

Limitations include the short experimental duration (30 days), which may not capture long-term effects on maturation or welfare, and the lack of physiological markers (e.g., cortisol, oxidative stress enzymes) to elucidate mechanisms. Temperature variation (18–22°C) could also confound results, as sterlet growth optima shift with age (Abdollahpour et al., 2021).

These findings contribute to sustainable sturgeon aquaculture by providing evidence-based guidelines for RAS optimization, balancing individual welfare with farm productivity. Future research should explore factor interactions, longer-term impacts, and economic modeling to refine commercial protocols.

Although the present study was conducted under highly controlled laboratory conditions in a recirculating aquaculture system (RAS), with stable hydrochemical parameters, precise oxygen regulation, and standardized feeding regimes, certain limitations should be acknowledged. The experimental duration was limited to 30 days and utilized small-scale tanks (0.64 m³), which may not fully replicate the fluctuations in water quality, hydrodynamic conditions, or long-term stressors encountered in commercial-scale sturgeon farms. Therefore, while the recommended parameters (dissolved oxygen 8–10 mg/L and stocking density 40–60 kg/m³) provide valuable guidelines for optimizing juvenile sterlet growth in RAS, field validation under full-scale

commercial production conditions is recommended to confirm their applicability and economic viability in practical aquaculture settings.

Conclusion

Under the conditions of a recirculating aquaculture system (RAS), a dissolved oxygen concentration of 8–10 mg/L was identified as optimal for maximizing growth and production performance. This oxygen range ensured the highest absolute weight gain (46.1 g), average daily gain (1.54 g/day), relative weight gain (64.1%), and specific growth rate (1.65%), as well as the maximum system productivity (36.4 kg/m³ and 29.1 kg/m²) and the lowest feed conversion ratio (FCR; 1.22). In the same RAS conditions, a stocking density of 40 kg/m³ provided the most favorable individual growth performance, whereas increasing the density to 80 kg/m³ resulted in a 17–21% reduction in growth rates compared with 40 kg/m³, potentially limiting production efficiency. Although a high stocking density (80 kg/m³) in RAS maximized total biomass yield and overall productivity (114.4 kg/m³ and 91.5 kg/m²), it adversely affected individual growth performance and feed efficiency, indicating a clear trade-off between biological performance and production output in intensive recirculating systems.

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Contribution of Authors

Shukurov M: Conceptualized the study, designed the methodology, validated results, prepared the original draft, contributed to visualization, and supervised the project.
Shumeyko D: Curated data and contributed to review and editing.
Sariyev B: Co-designed the methodology, conducted investigation, and co-wrote the original draft.
Arystangalieva V: Performed validation and reviewed the manuscript.
Ginayatov N: Conceptualized the study, provided resources, reviewed and edited the manuscript, supervised and administered the project, and secured funding.
Abdessan R: Conducted formal analysis, curated data, reviewed and edited the manuscript, and contributed to supervision.
Brigida A: Curated data and performed validation.
Albekov A: Carried out investigation and contributed to the original draft.
Bexultan A: Provided resources and contributed to review and editing.

All authors read and approved the final draft of the manuscript.

References

Abdollahpour H, Falahatkar B and Van der Kraak G, 2021. The effects of long-term thyroxine administration on hematological, biochemical and immunological features in sterlet sturgeon (Acipenser ruthenus). Aquaculture 544, 737065. https://doi.org/10.1016/j.aquaculture.2021.737065

Aidos L, Vasconi M, Abbate F, Valente LM, Lanfranchi M and Di Giancamillo A, 2019. Effects of stocking density on reared Siberian sturgeon (*Acipenser baerii*) larval growth, muscle development and fatty acids composition in a recirculating aquaculture system. *Aquaculture Research* 50:588-598. https://doi.org/10.1111/ARE.13936

Artem V, Brigida, Anastasiya S, Elizarova and Grigorii A and Shishanov, 2023. Influence of oxygen regimes of water on the physiological state of fish (review) 9. *Fish Breeding and Fisheries* 9: https://doi.org/10.33920/sel–09–2309–06

Boscari E, Vitulo N, Ludwig A, Caruso C, Mugue NS, Suciu R, Onara DF, Papetti C, Marino IA and Zane L, 2017. Fast genetic identification of the Beluga sturgeon and its sought-after caviar to stem illegal trade. *Food control* 75:145-152.

https://doi.org/10.1016/j.foodcont.2016.11.039

Bronzi P, Chebanov M, Michaels JT, Wei Q, Rosenthal H and Gessner J, 2019. Sturgeon meat and caviar production: Global update 2017. *Journal of Applied Ichthyology* 35:257-266. https://doi.org/10.1111/jai.13870

Bulbul Ali A and Mishra A, 2022. Effects of dissolved oxygen concentration on freshwater fish: A review. *International Journal of Fisheries and Aquatic Studies* 10:113-127. https://doi.org/10.22271/fish.2022.v10.i4b.2693

Chandra G and Fopp-Bayat D, 2021. Trends in aquaculture and conservation of sturgeons: A review of molecular and cytogenetic tools. *Reviews in Aquaculture* 13:119-137. https://doi.org/10.1111/raq.12466

Chebanov MS and Galich EV, 2013. Sturgeon hatchery manual: Subtitle.

Crocker CE and Cech JJJr, 1997. Effects of environmental hypoxia on oxygen consumption rate and swimming activity in juvenile white sturgeon, Acipenser transmontanus, in relation to temperature and life intervals. Environmental Biology of Fishes 50, 383–389. https://doi.org/10.1023/a:1007362018352

Dudu A and Georgescu SE, 2024. Exploring the Multifaceted Potential of Endangered Sturgeon: Caviar, Meat and By-Product Benefits. *Animals* 14:2425. https://doi.org/10.3390/ani14162425

Fazekas G, Káldy J, Kovács G, Müller T and Ljubobratović U, 2022. The effect of stocking density on sterlet Acipenser ruthenus (Linnaeus, 1758) larvae in the recirculating aquaculture system. J Appl Ichthyol 38, 479–486. https://doi.org/10.1111/jai.14341

Ginayatov N, Ulyanov V, Beishova I, Ulyanova T, Sidarova A, Kovalchuk A, Sariyev B, Kuzhebayeva U, Bakhareva A and Alikhanov K, 2024. Comparison of Genetic Diversity Indicators in Samples of Artificial and Natural Populations of Russian Sturgeon and Beluga at the Mouth of the Ural River. *Advancements in Life Sciences* 11:943-952. http://dx.doi.org/10.62940/als.v11i4.3458

Gosstandart, 1987. Stationary distillation desalting units. Methods of distillate chemical analysis: GOST 26449.2–85: Subtitle.

Ineno T, Kodama R, Taguchi T and Yamada K, 2018. Growth and maturation in sterlet Acipenser ruthenus under high concentrations of dissolved oxygen. Fish Sci 84, 605–612. https://doi.org/10.1007/s12562-018-1216-3

Jia R, Wang L, Hou Y, Feng W, Li B and Zhu J, 2022. Effects of stocking density on the growth performance, physiological parameters, redox status and lipid metabolism of *Micropterus salmoides* in integrated rice–fish farming systems. *Antioxidants* 11:1215. https://doi.org/10.3390/antiox11071215

Kurbanov A, Nomonov J, Titova N, Polaz S, Dziahtsiaryk S and Maksimyuk Y, 2024. Resistant Capabilities of the Sterlet (Acipenser Ruthenus) In Modeling the Impact of Stress Factors in the form of Increasing the Temperature of the Aquatic Environment, Decreasing Oxygen in the Aquatic Environment and Crowding. *Naturalisto campano* 28:1066-1076.

Lakin G, 1990. Biometrics. Textbook for the Biological Specialties of Universities, pp. 352. In (eds.), Moscow, The Higher School.

Li D, Liu Z and Xie C, 2012. Effect of stocking density on growth and serum concentrations of thyroid hormones and cortisol in Amur sturgeon, *Acipenser schrenckii*. *Fish physiology and biochemistry* 38:511-520. https://doi.org/10.1007/s10695–011–9531–y

Li L, Shen Y, Yang W, Xu X and Li J, 2021. Effect of different stocking densities on fish growth performance: A meta-analysis. *Aquaculture* 544:737152. https://doi.org/10.1016/j.aquaculture.2021.737152

Linhart O, Shelton W, Tučková V, Rodina M and Siddique M, 2016. Effects of temperature on in vitro short-term storage of Sterlet sturgeon (*Acipenser ruthenus*) Ova. *Reproduction in Domestic Animals* 51:165-170. https://doi.org/10.1111/rda.12661

Ljubobratović U, Bogár K, Káldy J, Fazekas G, Vass N, Feledi T and Kovács G, 2022. Optimizing the gonadoliberin dosage and evaluating the egg quality in the preseason and seasonal artificial reproduction of pond-reared sterlet *Acipenser ruthenus*. *Animal Reproduction Science* 247:107097. https://doi.org/10.1016/j.anireprosci.2022.107097

Lobanov VP, Combot D, Pelissier P, Labbé L and Joyce A, 2021. Improving plant health through nutrient remineralization in aquaponic systems. *Frontiers in plant science* 12:683690. 10.3389/fpls.2021.683690

Long L, Zhang H, Ni Q, Liu H, Wu F and Wang X, 2019. Effects of stocking density on growth, stress, and immune responses of juvenile Chinese sturgeon (*Acipenser sinensis*) in a recirculating aquaculture system. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology* 219:25-34. https://doi.org/10.1016/j.cbpc.2019.02.002

Obirikorang KA, Quagrainie K, Kassah JE and Von Ahnen M, 2024. Sustainable aquaculture production for improved food security. Frontiers Media SA.

Rafatnezhad S, Falahatkar B and Tolouei Gilani MH, 2008. Effects of stocking density on haematological parameters, growth and fin erosion of great sturgeon (*Huso huso*) juveniles. *Aquaculture Research* 39:1506-1513. https://doi.org/10.1111/j.1365–2109.2008. 02020.x

Ren Y, Wen H, Li Y, Li J, He F and Ni M, 2017. Effects of stocking density on lipid deposition and expression of lipid-related genes in Amur sturgeon (*Acipenser schrenckii*). *Fish Physiology and Biochemistry* 43:1707-1720. https://doi.org/10.1007/s10695–017–0403–y

Shcherbina M and Gamygin E, 2006. Feeding fish in freshwater aquaculture. *Moscow: VNIRO*

Tavakoli S, Luo Y, Regenstein JM, Daneshvar E, Bhatnagar A, Tan Y and Hong H, 2021. Sturgeon, caviar, and caviar substitutes: from production, gastronomy, nutrition, and quality change to trade and commercial mimicry. *Reviews in Fisheries Science & Aquaculture* 29:753-768. https://doi.org/10.1080/23308249.2021.1873244