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RESEARCH ARTICLE

# Preliminary rearing outcomes of Siberian sturgeon, *Acipenser baerii* Brandt, juveniles in autonomous hatching and rearing modules

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**Abstract**. This study analyzed the rearing indicators of Siberian sturgeon (*Acipenser baerii*) juveniles reared in tanks of different shapes and at various stocking densities. Rearing was conducted in autonomous hatching and rearing modules. Fish of an average body weight of 47.3±1.0 g were divided into four experimental groups: $C_L$, $R_L$, $C_H$, and $R_H$, which differed in stocking density (20 specimens and 50 specimens) and tank shape (C – circular, R – rectangular). The experiment ran for 28 days. Two-factor analysis indicated that lower stocking density significantly affected the final body weight of juvenile Siberian sturgeon, while tank shape had no effect on growth. The results of the current study on rearing Siberian sturgeon juveniles indicated that tanks of different shapes can be applied, but faster growth was obtained at a lower stocking density.

**Key words**: growth, Siberian sturgeon, stocking density, recirculating aquaculture system, tank shape

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## Introduction

In the last decade, the aquaculture sector has grown exponentially to meet the demand for easily digestible protein (FAO 2020). Most fish culture is conducted in various types of ponds and cages, but modern aquaculture is largely based on recirculating aquaculture systems (RAS) (Thomas et al. 2020). These systems have several ecological advantages including lower water consumption compared to other systems and easier disinfection and water purification (Nilav et al. 2020). Water reuse rates typically range from 80 to 99% depending on appropriate management practices (Morkunas et al. 2017). There are also possibilities for the productive use of wastewater and nutrients, which decreases the environmental impact and water consumption of aquaculture (Kloas et al. 2023). One of the great disadvantages of RAS, however, is its very high energy consumption, especially when the energy it consumes is from non-renewable resources or those that emit greenhouse gasses (Badiola et al. 2018). The further development of aquaculture will require applying improved technologies that can increase fish production, conserve water, and decrease environmental impacts (Pasch and Palm 2021).

Consequently, increasingly alternative energy produced by renewable energy resources (RES) are being used (Vo et al. 2021, Kloas et al. 2023). One example of this type of solution in aquaculture is the container hatching and rearing module powered by renewable solar energy. Stocking material of many different species of fishes and crayfish can be produced in these modules in RAS (Szkudlarek et al. 2021).

In Poland, Siberian sturgeon, *Acipenser baerii* Brandt, is one of the most frequently farmed sturgeon species from the family *Acipenseridae* (Bronzi et al. 2019). The success and spread of Siberian sturgeon culture are thanks to its high plasticity, reduced oxygen demand in the juvenile stage, and the high quality of the products derived (caviar, meat, and skins) (Gisbert and Williot 2002). Research on Siberian sturgeon has focused on, among other aspects, reproduction (Gisbert et al. 2000), nutrition (Rawski et al. 2020), health (Mugetti et al. 2020), and abiotic factors influencing cultured fish (Aidos et al. 2017, Simide et al. 2016). Because of the wide range of research conducted on this species, and well-understood culture methods, this species is a good research subject.

One of the significant factors of the biotechnology of fish culture in RAS is selecting appropriate rearing tanks. Tank size and shape (Akinwole and Akinnuoye 2012, Espmark et al. 2017) and water depth (Zhang et al. 2021) can all influence the growth of cultured fishes (Giovanni et al. 2016). Because of the way sturgeons feed, the most effective tanks have a large bottom surface area (Chebanov and Galich 2011). Studies on Chinese sturgeon, *Acipenser sinensis* (Gray), indicate that tanks of a small diameter and shallow water depth had a negative influence on growth and antioxidant processes (Zhang et al. 2021). Stocking density is also one of the most important factors to consider when rearing fishes in RAS since this most frequently influences growth, water quality, and fish welfare parameters (Oppedal et al. 2011, Manley et al. 2014, Yang et al. 2020). The dependence of fish welfare on stocking density means that determining optimal density is difficult because both too low and too high densities influence growth and fish welfare (Adams et al. 2007, Ni et al. 2016, Ruiz et al. 2021). Reactions to stress factors among sturgeons are not as pronounced as they are in other fish species. Even among closely related species there are species-specific differences regarding tolerance to stocking density (Ni et al. 2016, Rafatnezhad et al. 2008). Some studies have shown stocking density to have a negative influence on growth in beluga, *Huso huso* (L.) (Rafatnezhad et al. 2008), Atlantic sturgeon, *Acipenser oxyrinchus* Mitchill (Jodun et al. 2002, Szczepkowski et al. 2011), and Amur sturgeon, *Acipenser schrenckii* Brandt (Ni et al. 2016). High stocking density can lead to increased deformations, anomalous skeletal and muscular growth, and lowered survival in larval Persian sturgeon, *Acipenser persicus* Borodin, beluga, stellate sturgeon, *Acipenser stellatus* Pallas, and Siberian sturgeon (Mohseni et al. 2000, Aidos et al. 2018).

This study analyzed the rearing indicators of Siberian sturgeon juveniles reared in tanks of different shapes and at various stocking densities. The results will be helpful in the design of modern, highly efficient container modules for rearing Siberian sturgeon and other fish species.

## Materials and methods

The study material used in the experiment was obtained from artificial spawning conducted at the Department of Sturgeon Fish Breeding in Pieczarki, National Inland Fisheries Research Institute in Olsztyn. The experiment was conducted in three energy-efficient rearing modules located at Pieczarki. Two modules were equipped with four circular tanks (each measuring 1.10 × 0.88 m) and four rectangular tanks (each measuring 1.97 × 0.46 × 0.43 m) in a RAS. The third container was a technical module equipped with a retention tank, oxygenation columns, pumps, filters, a thermoregulation system with a solar heat accumulator, automated control, and pipelines to deliver and drain water from the rearing tanks in the modules.

Seven days before the experiment, 280 Siberian sturgeon were moved to the rearing containers and stocked into the circular and rectangular tanks for acclimatization. During this period, the fish were fed formulated feed twice daily at 10:00 and 16:00. Next, the fish were divided into four experimental groups that differed in stocking density and tank shape, as follows:

- group $C_L$ – circular tank with a stocking density of 20 specimens;
- group $R_L$ – rectangular tank with a stocking density of 20 specimens;
- group $C_H$ – circular tank with a stocking density of 50 specimens;
- group $R_H$ – rectangular tank with a stocking density of 50 specimens.

The initial average body weight, total length, and stocking density of the Siberian sturgeon are presented in Table 1. During the experiment, the fish were fed Aller Ivory (Denmark) 2 mm and 3 mm formulated feed (45% protein, 20% lipids 18% carbohydrates). The daily feed ration was 2% of the fish biomass (Kolman and Kapusta 2018), and the Siberian sturgeon were fed four time daily at 08:00, 14:00, 20:00, and 02:00.

Water quality parameters were measured weekly, and water temperature was monitored daily. Water oxygen concentration at tank outflows did not fall below 10.0 mg $O_2$ $l^{-1}$, and pH ranged from 7.5 to 7.9. The average water temperature was 16.8 ±1.8°C. Oxygen content and pH were determined with a CyberScan PCD 5500 (Eutech Instruments, USA). The maximum ammonium nitrogen and nitrite concentrations did not exceed 0.19 mg $l^{-1}$ or 0.11 mg $l^{-1}$, respectively, as determined with a spectrophotometer (Aquamate UV-Vis Plus). Water flow in the experimental tanks was 10 l $min^{-1}$. The duration of the experiment was 28 days.

Fish biomass and number were determined in each tank at the beginning and end of the experiment. Additionally, on days 1, 7, 14, 21, and 28 body weight (BW) was determined based on 10 specimens from each tank to determine the weekly feed ration. The data collected was used to calculate the following: specific growth rate (SGR) (% $d^{-1}$) = 100 × (ln $BW_2$ – ln $BW_1$) × $t^{-1}$; Fulton's condition factor (K) = 100 × $BW_m$ × $TL^{-3}$; coefficient of variation of body weight (CV,%) = 100 × SD × $BW^{-1}$; weight gain WG (%) = 100 × ($BW_2$ – $BW_1$) × $BW_1^{-1}$; feed conversion ratio (FCR) = TFC × (FB – IB)$^{-1}$; survival (S) (%) = 100 (FN × $IN^{-1}$); where $BW_1$ and $BW_2$ – and final body weight (g), $BW_m$ – average body weight (g); t – rearing time (days); TL – total length (cm); SD – standard deviation of body weight; IN and FN – initial and final number of fish (specimens); IB and FB – initial and final fish biomass (g); TFC – total feed consumed(g).

Statistical analysis was performed with Statistica 12.0 PL (StatSoft, Poland). Mean values and standard deviations (SD) are presented for measurements of 20 specimens from each experimental variant. One factor analysis of variance (ANOVA) was used to determine the significance of differences among rearing indicators (W, TL, K) in the groups analyzed. If the differences were statistically significant, further analysis was performed with Tukey's test at a significance level of $P \leq 0.05$. Data regarding final body weight were tested with two-factor MANOVA (tank shape and stocking density). The remaining rearing indicators (SGR, WG, FCR, S) were calculated from mean values of two replicates, but no statistical significance analysis was conducted because of the small number of replicates.

## Results

At the end of the experiment, the Siberian sturgeon in groups $R_L$ (112.8  25.5 g) and $C_L$ (117.2 ± 19.4 g) had the highest final body weights, which differed statistically significantly from groups $R_H$ and $C_H$, by 90.4 g and 93.4 g, respectively ($P < 0.05$; Table 1). The final total length of the fish from group $C_L$ (33.5 cm) was the longest and differed statistically compared to fish from groups $R_H$ (30.8 cm) and $C_H$ (31.2 cm) ($P > 0.05$; Table 1). The condition factor did not differ significantly among the experimental groups at 0.30–0.31 ($P > 0.05$). SGR and WG values were the highest in the variants with the low stocking density

**Table 1**

Initial and final rearing indicators of Siberian sturgeon reared in circular and rectangular tanks at different stocking densities (group $C_L$ – circular tank at a stocking density of 20 specimens, group $R_L$ – rectangular tank at a stocking density of 20 specimens, group $C_H$ – circular tank at a stocking density of 50 specimens, group $R_H$ – rectangular tank at a stocking density of 50 specimens) (mean values ± SD). Groups with the same letter index and in the same row do not differ statistically significantly (P> 0.05). *Rearing indicators (SGR, WG, FCR, S) were calculated from the mean values of two replicates

| Parameters | Group $C_L$ | Group $R_L$ | Group $C_H$ | Group $R_H$ |
|---|---|---|---|---|
| Initial body weight ($BW_i$, g) | $47.1 \pm 1.6^a$ | $46.0 \pm 0.9^a$ | $47.3 \pm 0.6^a$ | $48.9 \pm 0.9^a$ |
| Final body weight ($BW_f$, g) | $117.2 \pm 19.4^a$ | $112.8 \pm 25.5^a$ | $93.4 \pm 25.9^b$ | $90.4 \pm 18.3^b$ |
| Initial total length ($TL_i$, cm) | $24.8 \pm 1.3^a$ | $24.6 \pm 1.5^a$ | $24.3 \pm 2.1^a$ | $24.7 \pm 1.3^a$ |
| Final total length ($TL_f$, cm) | $33.7 \pm 1.8^a$ | $33.2 \pm 2.6^{ab}$ | $31.4 \pm 2.9^{bc}$ | $30.8 \pm 2.6^c$ |
| Initial Condition factor ($CF_i$) | $0.31 \pm 0.02^a$ | $0.31 \pm 0.04^a$ | $0.33 \pm 0.04^a$ | $0.32 \pm 0.01^a$ |
| Final Condition factor ($CF_f$) | $0.31 \pm 0.03^a$ | $0.30 \pm 0.02^a$ | $0.30 \pm 0.02^a$ | $0.31 \pm 0.03^a$ |
| Initial stocking density (kg $m^{-2}$) | $0.99 \pm 0.03^a$ | $1.02 \pm 0.02^a$ | $2.49 \pm 0.03^b$ | $2.72 \pm 0.05^c$ |
| Final stocking density (kg $m^{-2}$) | $2.47 \pm 0.06^a$ | $2.46 \pm 0.04^a$ | $4.86 \pm 0.09^b$ | $5.05 \pm 0.08^b$ |
| Specific growth rate (SGR, % $d^{-1}$)* | 3.26 ± 0.03 | 3.14 ± 0.12 | 2.39 ± 0.03 | 2.22 ± 0.01 |
| Weight gain (WG, %)* | 149.0 ±2.4 | 140.7 ± 8.4 | 95.2 ± 6.1 | 86.1 ± 0.1 |
| Feed conversion ratio (FCR)* | 0.50 ± 0.01 | 0.54 ± 0.02 | 0.55 ± 0.03 | 0.58 ± 0.01 |
| Survival (S, %)* | 100.0 ± 0.0 | 100.0 ± 0.0 | 100.0 ± 0.0 | 99.0 ± 1.4 |

(Table 1). The most advantageous FCR was obtained in group $R_L$ (0.50). Fish survival in the experimental groups was high (> 99.0%). The final body weight of Siberian sturgeon was not dependent on tank shape (P > 0.05), but stocking density influenced it (P < 0.001). However, no differences were noted in the influence of the combined factors of tank shape and stocking density on final body weight (Table 2, P > 0.05).

**Table 2**

Final body weights of Siberian sturgeon (mean [range]) after 28 days of rearing in different tanks (C – circular, R – rectangular) and at different stocking densities (L – 20 specimens, H – 50 specimens)

| Stocking density | Body weight (g) C | Body weight (g) R |
|---|---|---|
| L (n = 20) | 117.2 (88.0 – 168.0) | 112.8 (70.0 – 162.0) |
| H (n = 20) | 93.4 (58.0 – 142.0) | 90.4 (58.0 – 120.0) |
| *Manova* | | |
| Source | F | P |
| Tank shape (T) | 0.540 | 0.465 |
| Stocking density (D) | 20.986 | < 0.001 |
| T x D | 0.017 | 0.897 |

## Discussion

Sturgeons are among the world's most endangered fishes (IUCN 2023), which is why the only legal source of caviar and meat from them is aquaculture (Bronzi et al. 2019). Unfortunately, as aquaculture intensifies, cultured fishes are continually subjected to various stress factors, including high stocking density, that can influence survival and growth parameters. The higher stocking density applied in the present study influenced decreased growth in Siberian sturgeon, which is consistent with the results of studies on Amur sturgeon (Yang et al. 2011) and Atlantic sturgeon (Jodun et al. 2002). According to Wuertz et al. (2006), studies of shortnose sturgeon, *Acipenser brevirostrum* Lesueur, indicated that high stocking density is an environmental stress factor for older fish. However, Hasanalipour et al. (2013) report that stocking density did not influence Siberian sturgeon blood cortisol, glucose, or cholesterol levels. Aidos et al. (2020) report that larval Siberian sturgeon showed no changes in whole-body cortisol levels at different stocking densities and suggest that this is not a stress factor for early life stages of Siberian sturgeon when the hypothalamic-pituitary-adrenal axis is not yet fully developed. In many instances it is difficult to separate the direct negative effects of stocking density from secondary effects linked to stocking density such as the deterioration of water quality from ammonia and nitrite accumulation, oxygen deprivation, social interactions, and reduced feed intake (Barton 2002, Sloman et al. 2002, Ni et al. 2016). In the present study, the water quality parameters at the stocking densities applied were not factors that limited fish growth.

Higher stocking densities can influence higher numbers of interactions, which can significantly influence rearing results. Increased competition for feed usually leads to increased aggression among specimens (Kozłowski and Piotrowska 2022). Adult sturgeon rarely exhibit cannibalistic behaviors, but among juvenile beluga reared at high stocking densities increased numbers of specimens with damaged tail fins were noted (Rafatnezhad et al. 2008). This phenomenon was not observed in the current study probably because of the lower stocking densities. It appears that juvenile Siberian sturgeon do not exhibit aggressive behavior. Similar observations were reported during Atlantic sturgeon rearing (Mohler et al. 2000, Szczepkowski et al. 2011).

When rearing Siberian sturgeon of average body weights from 50 to 100 g, stocking density should not exceed 10 kg $m^{-2}$ (Kolman and Kapusta 2018). Köksal et al. (2000) report that Siberian sturgeon of body weights from 30 to 150 g should be reared at stocking densities of 2.4 and 11.5 kg $m^{-2}$, respectively. The stocking densities applied in the current experiment were lower or similar to those recommended by the authors cited above. The higher stocking density applied in the present study negatively influenced Siberian sturgeon SGR values, which ranged from 2.22 to 2.39% $d^{-1}$. The sturgeon grew faster at the lower stocking density (3.14–3.26% $d^{-1}$). Köksal et al. (2000) report that SGR values of Siberian sturgeon with body weights from 30 to 150 g was 2.8–2.2% $d^{-1}$, while Zare et al. (2009) report that Siberian sturgeon of an average initial body weight of 460 g that were reared at a high stocking density achieved SGR values of 0.83–1.13% $d^{-1}$. The stocking density of Amur sturgeon with an average initial body weight of 42 g had significantly better SGR values of 2.22% $d^{-1}$ at a low stocking density (Ni et al. 2016). Reduced growth at high stocking densities is attributed to increasing energy requirements to compensate for stress (Refaey et al. 2018, Long et al. 2019). Further, feed competition and fish activity can increase at higher stocking densities, which could stem from increased energy expenditure leading to lower FCR values (Kebus et al. 1992).

Tank shape in the current study had no influence on SGR or WG values in Siberian sturgeon. These results differ from those obtained during a study on rearing Chinese sturgeon, in which tank diameter and depth significantly influenced SGR and WG values (Zhang et al. 2021); these authors suggest that the shallower water depth was the primary stress factor that inhibited growth in Chinese sturgeon reared in a RAS. According to these authors, Chinese sturgeon should be reared in tanks of a diameter greater than 2.5 m and of a water depth of 0.6 m. In the present study, the fish were reared in tanks with water depths of 0.43 and 0.88 m, but the shallower depth did not influence fish growth.

In the current study, stocking density was not observed to affect the FCR values of Siberian sturgeon, which could indicate that the digestion and assimilation of the feed was not affected by the higher stocking density. Similar results were obtained in the rearing of fringebarbel sturgeon, *Acipenser nudiventris* Lovetsky, and Amur sturgeon (Ni et al. 2016, Feshalami et al. 2019). These results differ from those obtained with other sturgeon species, such as beluga and Atlantic sturgeon, in both of which the adverse effects of increased stocking density resulted in increased FCR values and lower growth (Rafatnezhad et al. 2008, Szczepkowski et al. 2011). Differences in the tolerance of stocking density among sturgeon species indicates species-specific differences among them.

Similarly to other sturgeon species (Rafatnezhad et al. 2008, Szczepkowski et al. 2011, Ni et al. 2016, Zhang et al. 2021), neither stocking density nor tank shape influenced the survival of the Siberian sturgeon in the present study. Survival in all the groups tested was high, which indicated that the stocking densities and tanks tested for Siberian sturgeon rearing were appropriate. According to Aidos et al. (2020), larval Siberian sturgeon in the yolk-sac resorption phase (0–8 days post hatching) were sensitive to high stocking density, while following this phase, this factor did not affect larval survival.

The present study also revealed that neither stocking density nor tank shape influenced the condition factor values, which is a good indicator of fish health. Similar results were noted when rearing lenok, *Brachymystax lenok* (Pallas), (Zhang et al. 2008) and Atlantic sturgeon (Szczepkowski et al. 2011); however, when rearing beluga and Amur sturgeon, better condition factor values were noted at low stocking densities (Rafatnezhad et al. 2008, Ni et al. 2016).

In conclusion, the present study analyzed the influence of different stocking densities and tank shapes on the rearing indicators of Siberian sturgeon reared in container hatching and rearing modules. The study confirmed that the lower stocking density was more advantageous at this stage of rearing, while tank shape did not affect the rearing indicators analyzed. However, fish culture at such low stocking densities is not economically viable in commercial aquaculture. This is why choosing a high stocking density could be a good compromise between fish growth and economic profitability. If rearing is to serve the purposes of conservation aquaculture with the aim of restoring populations, rearing fishes at very low densities could be important in increasing the successful introduction of them to their natural habitats.

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