IOP Conference Series:
Earth and
Environmental Science

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To cite this article: György Deák *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1216** 012021

Captive growth analysis of Siberian sturgeon juveniles (*Acipenser baerii* J. F. Brandt, 1869) fed on a commercial fodder and its importance to a sustainable development of the aquaculture sector

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Abstract. Sturgeon aquaculture is an important continuously developing sector within freshwater aquaculture and its sustainability is one of the most pressing matters nowadays. Thus, the urge to apprehend the mechanics of sturgeon growth in captivity as well as in nature is of immediate importance, considering the increase in customers' requests for captive-grown sturgeon meat, caviar, and adjacent by-products. The present study evaluates several canonical growth indices in a controlled, indoor environment that included fluctuations in temperature, dissolved oxygen saturation, and ponderal density (g/L), known to affect sturgeon growth performance. Over the 91 days of evaluation, no significant correlation was found between the weight gain and the ponderal density, dissolved oxygen values, and temperature, among the 4 tanks used in the experiment setup, indicating, along with the lack of significant variance for the RCI per tank, that the growth observed is correlated only with the fodder fed to the fish.

1. Introduction

Natural stocks of sturgeons have been decreasing dramatically all over the world, leading to the implementation of protection and conservation measures, such as fishing regulation, habitat restoration, and juvenile stocking. However, sturgeon farming now yields more than 2000 t per year, thus contributing to the reduction of fishing pressure and rehabilitation of wild stocks [1]. Considerable efforts have been made to improve the farming conditions of the species to counter the over-exploitation of natural populations [2], and subsequently standardize the growing conditions. While, at least for Romania and the EU zone, sturgeon research in the wild developed at a fast pace, addressing various problematics, from age determination [3,4], telemetry [5–8], selection of reproduction habitats [9], body mass mathematical modeling [10] and migration [5,6,11–15], in what concerns captive growth and breeding of the endangered sturgeon species, the scientific interest was significantly lower.

Environmental temperature and oxygen saturation are known to affect sturgeon development and physiology even at the larval state [16] as temperatures above 22 °C induce in *A. baerii* an increase in cortisol levels as a result of a probably higher metabolic rate. Although it is not yet fully understood if the species is sensitive to thermal stress [16,17], indications are given to keep captive stocks under strict temperature and oxygenation control regimes, as temperature fluctuation (as well as hypoxic conditions) enhance reactive oxygen species levels which can lead to changes in gene expressions [18]. The study evaluates how small fluctuations in temperature and dissolved oxygen concentration, reflecting the values found in the natural environment during the study period, could affect sturgeon growth. As most sturgeon species feed at the benthic level, they are dependent on the quantity and the quality of prey available and therefore are adversely affected by the accumulation of toxic compounds in sediments and the trophic web [1]. Therefore, we found that a standardized feed trial under such conditions was required before other feed conversion growth rate studies. In this study the growing rate of *A. baerii* was analyzed by using a standardized fodder with the final results allowing an eventual extend of the experiment to different types of provender and de novo additives in order to ensure better growth performance of this taxon.

2. Materials and Methods

The study was conducted in a specially designated precinct and involved 27 juvenile specimens tagged (T-bar tags, Hallprint, Australia) for individual recognition and hosted in 4 glass fiber tanks of 1.5 m^3 each, at occupancy rates of 0.466 – 0.533 %, individual density (individuals / 100 L) given by a ponderal expression of 1.3 (min.) – 2.07 (mean) – 3 (max.) g/L.

After an accommodation and acclimatization period of 2 weeks, daily feeding rates on the commercial sturgeon fodder (Coppens Supreme 4.5, Alltech, Germany) were applied consistently at a rate of 1.5% of the whole same-tank batch weight and varied accordingly to the weight gain observed for each weighing and measuring session. Biometrical (total length, standard length, head circumference, body circumference, caudal peduncle circumference, and ponderal data weight) collection was carried out on a 2 weeks basis, as a general rule, for the whole stock of 27 individuals.

Dissolved oxygen concentration (mg/L) and water temperature (°C) were recorded for each measuring session (HQ40D, Hach-Lange, UK). The whole trial period covered 7 measurement sessions over a total of 91 days. The periods were consensually noted T0-T6, as follows:

Table 1. Codes used for the measurement sessions

Measurement date	21.06.2022	05.07.2022	19.07.2022	03.08.2022	23.08.2022	07.09.2022	20.09.2022
Period code	T0	T1	T2	T3	T4	T5	T6

2.1. Growth Performance

Before computing the simple regression of the Length-Weight data, a normal distribution test (Shapiro-Wilk and Anderson-Darling tests) was performed for the values of both length and weight, as total values for all the tanks as well as per individual tank. The results indicated that the data follow a normal distribution in all cases. A Pearson correlation coefficient test was applied, returning values of r = 0.941

and of $R^2 = 0.9042$ for the coefficient of determination, indicating there is a strong correlation between the length and weight measurements.
Growth performance was investigated by computing the following indices:

$Weight\ gain\ (WG) = Mean\ final\ weight\ (Wm) - Mean\ initial\ weight\ (Wi)$ [20–24]

$Percentual\ (\%)\ weight\ gain\ (PWG) = \frac{\text{Mean final weight (Wmf) – Mean initial weight (Wmi)}}{Mean\ initial weight\ (Wmi)} x100$ [21,25-28]

$Specific\ growth\ rate\ (\%)\ per\ day\ (SGR) = \frac{ln\ (W2) - ln\ (W1)}{t\ (days)} x100$ [21,22,24–27,29,30]

$Feed\ conversion\ ratio\ (FCR) = \frac{Total\ amount\ of\ feed\ consumed\ (Wm)}{Wet\ weight\ gain\ (Wmf - Wmi)}$ [21,22,29]

$Daily\ weight\ gain\ (DWG) = \frac{Mean\ final\ weight\ (Wmf) - Mean\ initial\ weight\ (Wmi)}{t\ (days)}$ [21,25–28]

$Relative\ condition\ index\ (RCI) = \frac{Observed\ weight\ (Wo)}{Calculated\ weight\ (Wc)}$ [23,25–28,31–36]

All statistical analysis employed the XLSTAT patch for Microsoft Excel [36].

Simple regression was employed for calculations regarding the Length – Weight correlation, and both values for length and weight were tested for normal distribution. Figure 1 illustrates the biometric measurement method used by INCDPM team.

Figure 1. Biometric measurements of every single *A. baerii* individual was conducted once every two weeks.

3. Results

3.1. Descriptive Statistical Data

The descriptive statistics concerning the minimum, mean and average body weight and various lengths as well as the respective standard deviations and coefficients of variance for each tank are presented in Table 2.

Table 2. Descriptive statistics for biometric, ponderal, and physical – chemical parameters per tank

Tank	Values	Weight (g)	Total length (cm)	Standard length (cm)	Head girth (cm)	Body girth (cm)	Tail girth (cm)	T°C	Dissolved oxygen mg/L	Total biomass (g)	Ponderal density g/L
4	Min	125.40	35.00	28.00	10.50	11.50	4.00	21.50	7.32	2011.200	1.3408
	Mean	421.48	47.69	36.94	14.22	16.54	5.18	23.48	8.03	2880.083	1.9201
	Max	783.40	60.00	46.00	17.80	20.00	6.50	24.90	8.45	3807.000	2.5380
	SD	157.70	6.27	4.51	1.49	2.12	0.56	1.36	0.41	774.172	0.5161
	CV	0.37	0.13	0.12	0.10	0.13	0.11	0.06	0.05	0.269	0.0002
3	Min	111.60	33.00	15.50	10.00	10.50	3.00	21.50	5.86	2004.400	1.3363
	Mean	437.01	58.16	37.86	15.03	16.40	5.08	23.66	7.31	3059.057	2.0394
	Max	751.80	473.60	52.70	40.70	19.50	7.00	24.90	8.52	4058.600	2.7057
	SD	6.74	14.35	3.40	4.07	1.86	2.33	1.16	1.45	2.025	0.0002
	CV	0.02	0.25	0.09	0.27	0.11	0.46	0.05	0.20	0.001	0.0001
2	Min	204.60	43.00	33.00	12.00	12.30	4.00	21.50	5.36	2199.200	1.4661
	Mean	495.62	52.38	40.20	15.14	17.10	5.32	23.57	7.30	3327.743	2.2185
	Max	843.60	63.00	49.00	17.50	21.00	6.50	24.90	8.62	4500.500	3.0003
	SD	178.84	5.59	4.61	1.51	2.27	0.57	1.38	1.34	887.548	0.5917
	CV	0.36	0.11	0.11	0.10	0.13	0.11	0.06	0.18	0.267	0.0002
1	Min	130.70	34.50	26.50	10.30	11.00	3.60	21.50	6.75	1950.300	1.3002
	Mean	415.23	48.25	36.61	14.14	16.29	5.03	23.67	7.51	3203.200	2.1355
	Max	789.30	61.30	46.00	17.80	21.00	7.40	24.90	8.45	4354.100	2.9027
	SD	174.23	7.34	5.47	1.96	2.49	0.80	1.34	0.67	956.538	0.6377
	CV	0.42	0.15	0.15	0.14	0.15	0.16	0.06	0.09	0.299	0.0002

3.2. Length-Weight Relationship and Relative Condition Index

The Length–Weight relationship for all the specimens in the 4 tanks is expressed further on as a relative condition factor [28,30,32,34,35,37,38] (the ratio of the observed weight (Wo) and the calculated weight (Wc) throughout simple regression at a given length fitted the formula of a power function of type $Wc = aL^b$) consistent with the available literature on the topic [27,31,32], and returned values for parameters a and b of 0.0042 and 2.9525, also identified in previous studies for *A. baerii* [22,23,39,40, 41] (Figure 2).

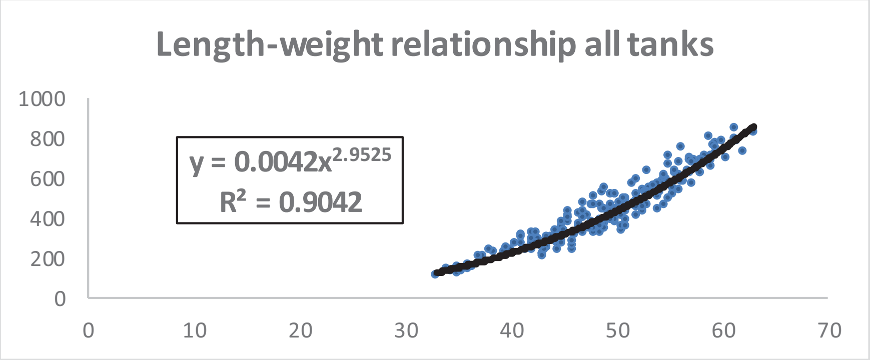

Figure 2. Length – Weight relationship for A. baerii.

Variation for the a and b parameters of the length-weight relation was tested (CV%), among all 4 tanks, and the values indicated there is no significant variation between the respective coefficients of the tanks. The values and the plots for each tank are shown in table 3 and figure 3.

Table 3. Variation for parameters a, b, and R^2 values among the 4 tanks setups

	Tank 1	**Tank 2**	**Tank 3**	**Tank 4**	**Mean**	**SD**	**CV**
Parameter a	0.0054	0.005	0.0032	0.005	0.00465	0.000985	21.18034
Parameter b	2.8855	3.4962	3.0176	2.9239	3.0808	0.282436	9.167634
R^2 value	0.9178	0.937	0.8661	0.9304	0.912825	0.032152	3.522272

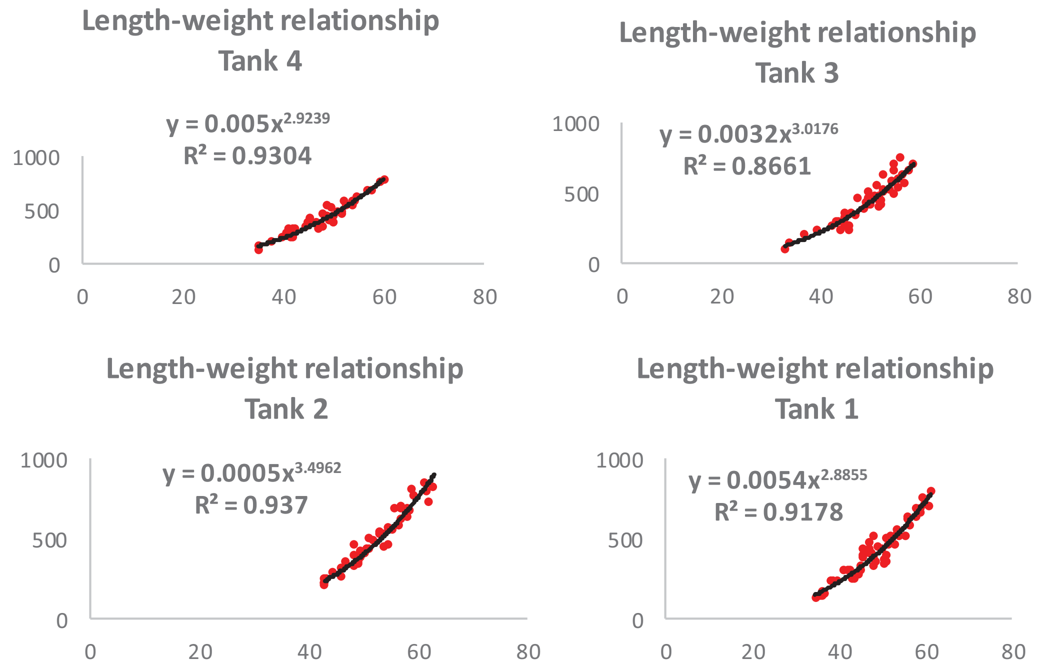

Figure 3. Compared scatterplots for the length-weight relationship values among tanks

The values of RCI varied, both in time and by tank, being lower at the beginning of the experiment when the acclimatization period of 2 weeks influenced the following measurement sessions and increased significantly after the T3 measuring session. The overall values of the dispersal of the RCI values against the ideal, unitary value (when all individuals grow according to the Length-Weight equation) are presented in figure 4.

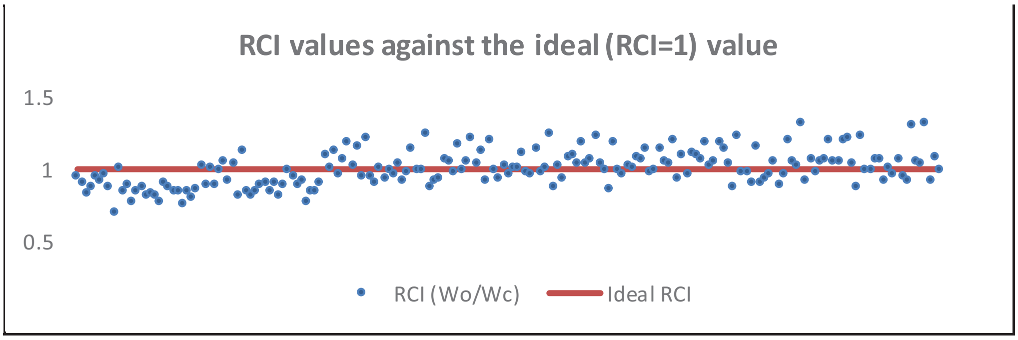

Figure 4. RCI values against the ideal value

The percentage of individuals with values of the Relative Condition Index higher than 1 (the ideal condition, when sampled individuals have the same observed weight as the one calculated employing the Length-weight regression) increased as a time function during the experiment, returning values of 3.7% in the first session of measurements(1 individual of Good Condition Index of a total of 27 individuals tested), and up to 66% in the last session of measurements (18 individuals of Good condition Index of a total of 27 individuals tested), as evolution in time of the relative condition index for *A. baerii*. Sampled data as relative condition index for *A. baerii* are presented in table 4 and figure 5.

Table 4. Relative Condition Index values in time (number of individuals (%))

	RCI<1 (poor condition index)	RCI>1 (good condition index)
T0	26 (96.99%)	1 (3.7%)
T1	21 (77.77%)	6 (22.22%)
T2	14 (51.85%)	13 (48.14%)
T3	10 (37.03%)	17 (62.96%)
T4	7 (25.92%)	20 (74.07%)
T5	11 (40.74%)	16 (59.25%)
T6	9 (33.33%)	18 (66.66%)

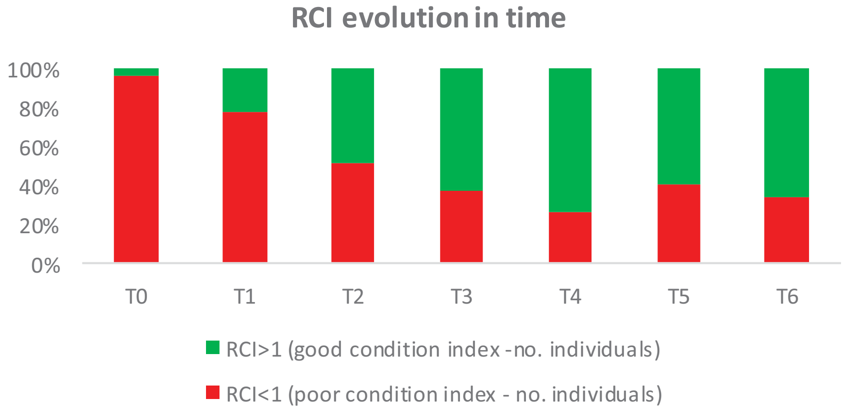

Figure 5. Evolution in time of the Relative Condition Index

3.3. Weight gain

The mean weight gain (g) was calculated for each tank, as the difference between the final (T6) mean weight (Wm) and the initial (T0) mean weight, for each of the experimental tanks. The values are presented in table 5. Further on, the values of the Mean weight gain were tested for correlation (Pearson's correlation coefficient) with all the parameters for the tested tank, respectively, ponderal density (expressed as total biomass in grams per volume), dissolved oxygen, and temperature. No significant correlation could be identified. We can thus conclude that the mean weight gain was not influenced by either of the respective parameters. Percentual weight gain was computed as the same value as the mean gain weight but expressed in percent of the initial weight.

Table 5. Weight gain and tank parameters

Tank	Mean weight gain (g)	Mean percentual weight gain (%)	Mean ponderal density (g/m^3)	Mean dissolved oxygen (mg/L)	Mean T°C
4	571.57	217.29	1.92	8.03	23.48
3	534.87	197.61	2.04	7.31	23.66
2	610.58	190.31	2.22	7.30	23.57
1	569.76	290.02	2.14	7.51	23.67

3.4. Growth parameters

The growth parameters (SGR, DWG, and FCR) were computed per tank and per period (T0 – T6), followed by an all-time/tank approach, based on either summed (total food intake) or average values (particular indices were taken into account). The values for the specific growth rate differed in some cases from those mentioned by previous works [21] , probably due to the choice of formula employed, since some authors used a log of the difference between the final and the initial weight, while others preferred an ln (natural logarithm). Our data are significantly similar to those papers where an ln interpretation was employed (similar to the present case) [21,24,28].

The daily weight gain was similarly computed by employing an individual-focused approach rather than choosing central tendency indicators and taking into consideration the difference between the final and the initial weight of each fish sampled.

The same principles were used for the feed conversion rate, where individual feed quantities were computed for each fish over a period of 14 days, then the respective results were summed up to compute the individual total feed intake per tank over the entire experiment duration. Total individual feed intake was divided by the weight gain and returned as individual feed conversion rate.

The mean values for the said parameters are presented in Table 6 and Figure 6. Similarly, to the weight gain indicators presented above, no significant correlation was identified between the SGR, DWG, or FCR and the tank parameters. It can be confirmed with a confidence level of 85% that the batches in the four different tanks are homogeneous.

Table 6. Mean values of the employed growth parameters per tank

	Tank 4	Tank 3	Tank 2	Tank 1
Mean DWG (g/day)	6.28	5.88	6.71	6.26
Mean SGR	0.90	0.82	0.75	1.08
Total food	318.10	321.20	349.41	336.34
Daily feeding rate	3.50	3.53	3.84	3.70
Mean FCR (g/g)	3.87	4.30	5.13	3.42
Mean ponderal density (g/L)	1.92	2.04	2.22	2.14

Mean dissolved oxygen (mg/L)	8.03	7.31	7.30	7.51
Mean T°C	23.48	23.66	23.57	23.67

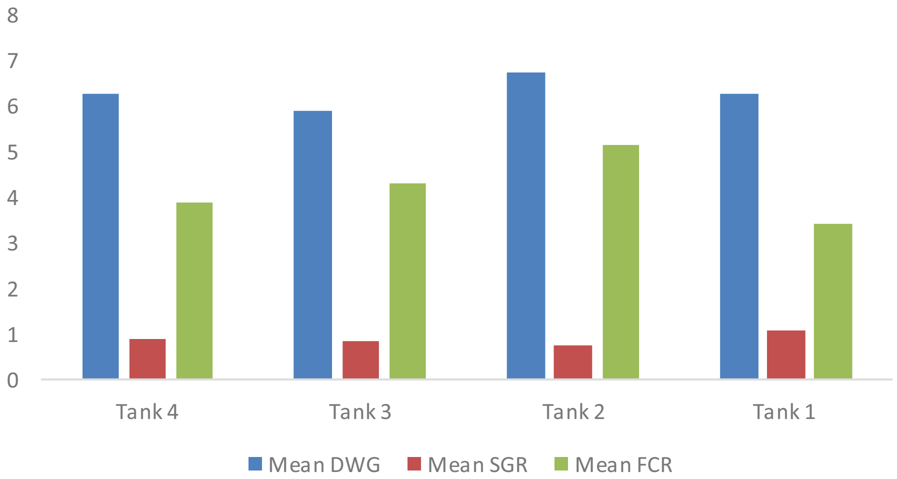

Figure 6. Mean values per tank for the growth indices employed

4. Conclusions

The study concludes that the slight variations in dissolved oxygen and temperatures, as well as the ponderal density within the tanks did not influence significantly the growth of the *A. baerii* juveniles, according to the variation of the growth indices taken into account, as well as the lack of significant correlation between the values of the said indices and the values of the tank parameters. We can thus conclude that in a stable indoor environment, where there are no significant fluctuations of dissolved oxygen, temperature, or fish stock density, the growth can be explained solely as a function of the food intake. The observation is valuable (with a 85% confidence level) since it provides the framework for comparative studies of different feeding ratios of the same fodder, or of similar ratios for different composition fodders, where the growth variation can be consistently correlated to the qualitative or quantitative parameters of the fodder since no significant bias can be related to environmental variations.

The Length–Weight relationship obtained by simple regression of the measured total length and weight was reliable and correlated to the data presented in similar papers. This, along with the relative condition index, rendered quick and prompt responses to the growth-induced modifications in the sampled populations.

In conclusion, the *A. baerii* population homogeneity in the four different-conditioned tanks ensures favourable prerequisites in order to extend the results to superior, more complex experiments which will allow to study oxidation stress levels that can occur with the introduction of different fodder additives in the diet as well as their effects on the growth performance of the individuals.

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