Scientific Papers. Series D. Animal Science. Vol. LXIX, No. 1, 2026
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

LENGTH–WEIGHT RELATIONSHIP AND GROWTH OF ARTIFICIALLY REARED DANUBE SALMON (*Hucho hucho*, Linnaeus 1758)

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Abstract

The Danube salmon, Hucho hucho (Linnaeus, 1758), is a species of high economic and conservation interest, for which aquaculture plays an essential role in stock maintenance and restocking programs. This study presents biometric and growth-related information on H. hucho specimens reared under controlled farming conditions at the Valea Bistrişorii Trout Farm, Alba County, Romania. Fish were captured using routine aquaculture handling methods and measured to assess the length-weight relationship and relative condition factor. The results indicated a positive allometric growth pattern, suggesting suitable rearing conditions. The relative condition factor showed variation among individuals, reflecting differences in growth performance within the stock. These findings provide useful data on the growth characteristics of farm-reared Danube salmon and support the importance of aquaculture facilities in research and management of this species.

Key words*: biometric assessment, captive rearing, growth performance, salmonid culture, stock management.*

INTRODUCTION

The Danube Salmon (*Hucho hucho)* is regarded as one of the most distinctive and aesthetically remarkable species within the Salmonidae family, owing to its morphological features and significant ecological role. The species exhibits an impressive and elegant appearance, with adult individuals frequently exceeding 1 meter in total length in natural environments (Holčík et al.,1988; Ihuț et al., 2014; Kottelat & Freyhof, 2007). Its morphology is characterized by a streamlined, fusiform body adapted to fast-flowing waters, a large head, and a silvery coloration with brownish-red reflections, all of which contribute to its aesthetic and biological value (Holčík et al.,1988; Ihuț et al., 2014).

From an ecological perspective, *Hucho hucho* functions as an apex predator in montane river ecosystems, playing a crucial role in maintaining trophic balance. The species is endemic to the Danube River basin and is currently undergoing a pronounced population decline (Ford, 2024). The Danube Salmon inhabits cold, well-oxygenated, and highly natural river sections, which makes it a reliable indicator of minimally disturbed freshwater ecosystems. It inhabits cold, well-oxygenated, natural river sections, making it a reliable indicator of minimally disturbed freshwater ecosystems. Its conservation depends on preserving river habitats in the Danube basin; therefore, it is widely recognised as a flagship species for conservation strategies (Ihuț et al., 2014; Pinter et al., 2024). The European huchen *(Hucho hucho)* is an endangered salmonid flagship species, yet detailed biological parameters for populations under intensive

culture remain disproportionately scarce compared to their wild counterparts. The present study establishes an important reference point that complements existing literature, enabling the comparison of growth patterns across different environments. Integrating these data with previous research provides the necessary framework to quantify how habitat degradation impacts the species' physiological fitness.

This study aims to evaluate the growth patterns and physiological status of *Hucho hucho* over three years (2013-2015) using length-weight relationships (LWR) and condition indices. By comparing Fulton's (*K*) and relative (*K*n) condition factors, the research seeks to identify inter-annual variations in fish well-being and determine the specific type of allometric growth. These findings provide essential baseline data for the monitoring and sustainable management of this species in its natural habitat.

MATERIALS AND METHODS

Fish Rearing Conditions and Feeding Regime

Huchen *(Hucho hucho)* specimens were reared in a conventional concrete tank (2.2 m × 2.0 m) under a continuous flow-through water system. The experimental stock consisted of 150 individuals belonging to the same age cohort, reared under identical conditions in a single concrete flow-through tank. Each month, 50 fish were randomly sampled from the tank and individually weighed. As fish were not individually marked, sampling was conducted at the population level and did not involve tracking of specific individuals over time. The mean initial body weight (BW) was 22.45 ± 0.79 g, and the mean total length (TL) was 14.25 ± 0.167 cm. Fish were fed commercially formulated diets produced by Aqua Garant, with pellet size adjusted according to age class and developmental stage. The feeding program included Aqua Start 1.5 mm pellets for fry weighing 5-15 g and measuring 8-13 cm TL; Aqua Dynamic 2 mm pellets for juveniles weighing 15-50 g and measuring 13-18 cm TL; Aqua Dynamic 3 mm pellets for fish weighing 50-150 g and measuring 18-25 cm TL; and Aqua Dynamic 4 mm pellets for huchen weighing 150-350 g and measuring 25-33 cm TL. Feed was provided ad libitum using an automatic feeder throughout the study period. The water temperature in this salmonid rearing unit fell within the optimal range for salmonid culture, ranging from a minimum of 2.6°C in December to a maximum of 19.3°C in August.

Ethical approval

This study was approved by the Animal Ethics Committee of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca (Approval No. 117/2018).

Fish body measurements

The morphometric data collection followed the general principles for fish analysis. For each specimen, two primary parameters were recorded: total length (TL) and body weight (BW). Total length was measured from the tip of the snout to the end of the caudal fin (to the nearest 0.1 cm), while body weight was determined using a high-precision digital balance (to the nearest 0.01 g) (Lațiu, 2025).

Length-weight relationship

The length-weight relationship (LWR) was estimated using the power function $BW = aTL^b$. To linearize the relationship, the data were log-transformed: log BW = log a + b log TL, where BW is the wet body weight of fish, TL is the total length, a is the intercept of the regression and b is the slope of the regression. To assess the growth type, the calculated allometry coefficient (b) was compared against the theoretical isometric value ($b = 3$) using the Student's t-test: $ts = (b - 3)/Sb$. Growth was categorized as isometric ($b = 3$), positive allometric ($b > 3$), or negative allometric ($b < 3$) (Le Cren, 1951; Froese, 2006; Simonović et al., 2011).

Condition factors

The physiological status of the specimens was evaluated using two complementary indices:

Fulton's Condition Factor (*K*): Calculated as $K = 100 * (BW/TL^3)$, where BW is the body weight (g) and TL is the total length (cm). In this isometric model, the power of 3 reflects the cube law, assuming that fish shape and density remain constant as the fish grows.

Relative Condition Factor (*K*n): Calculated as $Kn = BW_o/BW_p$, where BW_o is the observed weight and BW_p is the predicted weight derived from the specific LWR of the population ($BW = aTL^b$). Fulton's condition factor was used to compare the general well-being assuming a cubic growth, while the relative condition factor was included to compensate for the allometric

growth observed in specific years (Froese, 2006; Lațiu et al., 2023).

Fish sampling

All analyzed specimens of *Hucho hucho* originated from the same population. The variation in the number of individuals across the sampling years (2013, 2014, and 2015) resulted from a non-standardized, opportunistic sampling strategy. Data collection was performed across different months within each year, and the sample sizes reflect the natural availability and accessibility of the specimens during those specific periods. Consequently, the fluctuating number of individuals per year represents a series of seasonal snapshots of the same population rather than a pre-determined experimental design.

Statistical Analysis

Condition indices (*K* and *K*n) were compared across the sampling years (2013, 2014, and 2015) and for the pooled dataset. Data normality was assessed using the Shapiro-Wilk test. Since the data deviated significantly from a normal distribution, non-parametric methods were employed. The Kruskal-Wallis *H* test was used to identify overall differences between groups, followed by Dunn's post-hoc test for pairwise multiple comparisons to determine specific inter-annual variations.

All statistical analyses and graphical representations were performed using GraphPad Prism version 8.0.1 (GraphPad Software, San Diego, California, USA). The threshold for statistical significance was set at alpha = 0.05.

RESULTS AND DISCUSSIONS

Fulton condition factor K

Descriptive statistics for Fulton's condition factor (*K*) showed an overall mean of 0.8485 ± 0.1004. The lowest mean condition was recorded in 2013 (0.7663 ± 0.049), while the highest values were observed in 2014 (0.8695 ± 0.111) and 2015 (0.8614 ± 0.068). The coefficient of variation was notably higher in 2014 (12.87%), indicating a wider disparity in fish physiological status during that period compared to the more homogenous group from 2013 (6.43%). Regardless of the year, the low standard error of the mean (SEM < 0.005) indicates high reliability of the estimated indices.

The Kruskal-Wallis test revealed highly significant differences in the condition factor (*K*) across the studied periods ($H = 246.4$, $p < 0.0001$). Subsequent pairwise comparisons using Dunn's post-hoc test showed that the condition of fish in 2013 was significantly lower than in all other groups, including the pooled dataset ($p < 0.0001$ for all comparisons involving 2013).

In contrast, no significant difference was observed between the years 2014 and 2015 ($p > 0.9999$, ns). Additionally, both 2014 and 2015 showed significantly higher condition indices compared to the overall pooled average ($p < 0.0001$ and $p = 0.0089$, respectively), suggesting that the physiological status of the population improved notably after the first study year.

Relative condition factor Kn

Descriptive statistics for the relative condition factor (*K*n) showed mean values very close to unity across all analyzed periods: 1.002 ± 0.064 in 2013, 1.008 ± 0.121 in 2014, and 1.003 ± 0.073 in 2015, with an overall pooled mean of 1.006 ± 0.118 (Figure 1). The Kruskal-Wallis test indicated no significant differences in *K*n among the studied years ($H = 5.206$, $p = 0.1573$). This lack of significance was further confirmed by Dunn's post-hoc test, which showed no significant pairwise differences between any of the analyzed years or the pooled dataset ($p > 0.05$ for all comparisons). These results suggest that when the specific allometric growth pattern of the population is taken into account, the relative physiological status of the fish remained remarkably stable throughout the study period, regardless of the variations observed in Fulton's condition factor.

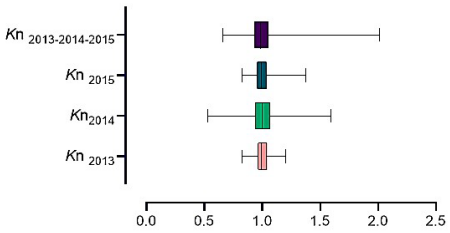


Figure 1. Relative condition factor *K*n

Length-weight relationship

All fish belonged to the same cohort, and the observed differences among years reflect

growth progression of the individuals over time. The length-weight relationship (LWR) parameters and growth patterns for *Hucho hucho* across the study periods are summarized in the table. For the years 2013 and 2014, the allometry coefficient (*b*) values were 2.964 and 2.971, respectively (Figure 2,3). The Student's t-test confirmed that these values did not differ significantly from the theoretical value of 3 ($t_{calculated} < t_{critical}$, $p > 0.05$), indicating an isometric growth (ISO) for these cohort.

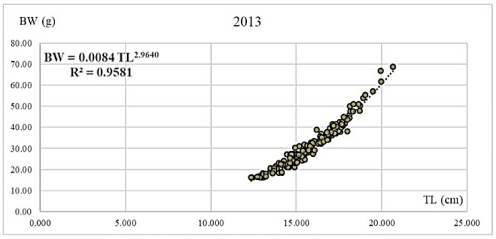


Figure 2. LWR of *H. hucho* in 2013

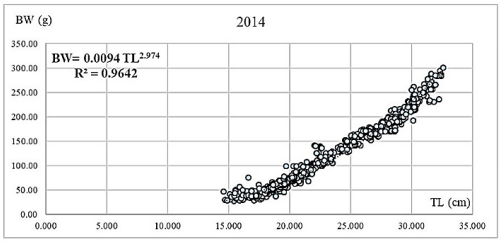


Figure 3. LWR of *H. hucho* in 2014

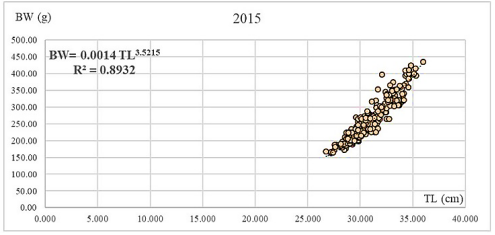


Figure 4. LWR of *H. hucho* in 2015

In contrast, the year 2015 showed a significantly higher allometry coefficient (*b* = 3.5215) (Figure 4) with the t-test revealing a highly significant difference ($t_{calculated} = 7.3824$, $p < 0.05$). This indicates a positive allometric growth (ALLO+), suggesting that the fish gained weight more rapidly relative to their length during this period. For the pooled dataset (2013-2015, n = 1100), the overall growth was also significantly positive allometric (b = 3.1020, $t_{calculated} = 8.6808$, $p < 0.05$). High coefficients of determination ($R^2 > 0.89$) were recorded for all models, demonstrating a strong correlation between length and weight across all sampled years.

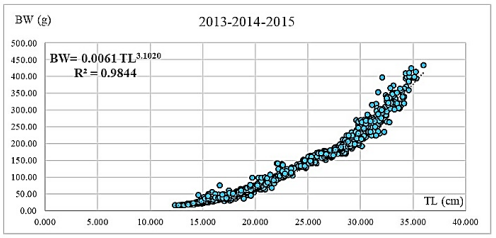


Figure 5. LWR of *H. hucho* in the 3 year analyzed period

Comparable studies on wild populations of *Hucho hucho* have reported b-values ranging from 3.25 to 3.39 (Andreji & Stráňai, 2013; Lațiu et al., 2022), indicating positive allometric growth under natural riverine conditions. For example, individuals from the Ruscova River (Romania) exhibited a b-value of 3.3879, which is consistent with the results obtained in the present study (Lațiu et al., 2022). Similarly, cultured populations have also shown positive allometric or near-isometric growth, with reported b-values ranging from 3.256 to 3.774, depending on rearing conditions and broodstock origin (Andreji & Stráňai, 2013). In contrast, Savić (2022), studying huchen fingerlings reared under cultivated conditions, reported a lower regression coefficient (b = 2.822), indicating negative allometric growth, together with a mean condition factor of 0.82. In addition, Simonović et al. (2011) emphasized that huchen growth is strongly influenced by both age and environmental conditions, with notable differences in growth performance between natural river systems and aquaculture settings. In the present study, huchen sampled during 2013 exhibited isometric growth. These results suggest a more balanced increase in length and weight during the juvenile stage,

Table 1. The length-weight relationship parameters and growth patterns for *Hucho hucho*

Year	N	Total length (mm)			Body weight (g)			Parameters of LWRs					Test-$t_{0.05}$		Growth type
		TL min.	TL. max	TL mean+-SD	BW min.	BW max.	BW mean+-SD	*a*	*b*	*a* CI95%	*b* CI95%	R^2	$t_{calculated}$	$t_{critical}$	
2013	200	12.35	20.66	15.74±1.623	16.15	68.73	30.84±9.916	0.00844	2.96404	0.00664-0.01073	2.87695-3.05113	0.95810	0.8142	1.972	*b*=3 (ISO)
2014	600	14.59	32.57	23.38±4.901	27.5	300.4	124.7±70.95	0.00945	2.97116	0.00818-0.01091	2.92515-3.01718	0.96420	1.2308	1.964	*b*=3 (ISO)
2015	300	26.75	35.96	30.92±1.825	163.3	434.4	258.8±58.83	0.001144	3.52154	0.00089-0.00231	3.38251-3.66057	0.89323	7.3824	1.968	*b*>3 (ALLO+)
2013/ 2014/ 2015	1100	12.35	35.96	24.05±6.338	16.15	434.4	144.2±99.16	0.00612	3.10205	0.00569-0.00658	3.07899-3.12512	0.98449	8.6808	1.9621	*b*>3 (ALLO+)

TL - total length; BW - body weight; SD - standard deviation;

a - the intercept of the regression; b - the slope of the regression.

representing an intermediate growth pattern between the negative allometric growth reported by Savić (2022) and the positive allometric growth observed in both wild and older cultured huchen populations.

Overall, these findings confirm that length-weight relationships in *Hucho hucho* vary considerably depending on age class and environmental conditions, with juvenile stages often showing more balanced growth patterns compared to later developmental stages or differently managed populations.

CONCLUSIONS

The study revealed significant inter-annual variations in the growth patterns and physiological status of *Hucho hucho*. The allometric growth shifted from isometric in 2013 and 2014 to positive allometric in 2015, indicating an increase in body robustness over time. While Fulton's condition factor (*K*) showed significant differences between years, suggesting a lower condition in 2013, the relative condition factor (*K*n) remained stable and close to unity throughout the study. This demonstrates that when accounting for the population's specific allometry, the overall well-being of the fish was consistently maintained across all sampling periods.

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