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EFFECTS OF CLIMATE CHANGE ON *Cyprinus carpio* (Linnaeus, 1758) IN THE DANUBE RIVER (2021-2024): ANALYSIS OF SEX RATIOS, CONDITION AND LENGTH-CLASS DISTRIBUTION

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Abstract

The common carp Cyprinus carpio (Linnaeus, 1758) is a key species in the Danube River, both ecologically and economically. The carp population in the Danube is affected by a range of factors such as overfishing, loss of habitats, pollution, anthropogenic disturbance and alien species. Climate change is putting an additional strain on these fish populations, altering parameters such as length and sex structure, Fulton’s condition factor. This study examines changes in these parameters within carp populations in the Danube based on data collected from 2021 to 2024. By comparing biometric and demographic indicators, this research identifies hydrological trends driven by climatic variations, and how the sex structure was also affected, with sex ratio depending on region and local climatic conditions. Fulton’s condition factor was calculated to assess the nutritional status and overall health of individuals in the population. This study highlights the urgent need for sustainable fisheries management and appropriate conservation strategies to address the challenges posed by climate change.

***Key words**: Danube River, fisheries management, Fulton’s condition factor, global warming, wild fish.*

INTRODUCTION

The Danube River, the second-longest river in Europe, represents a vital ecosystem, supporting rich aquatic biodiversity and providing numerous economic benefits (Ibanescu et al., 2016). Among the fish fauna species, the common carp *Cyprinus carpio* (Linnaeus, 1758) stands out due to its ecological and economic importance. I

t is one of the most widely distributed freshwater fish species globally (Cocan & Miresan, 2018; Anin et al., 2021; Dobrota et al., 2024), playing an essential role in maintaining aquatic biodiversity and supporting fisheries.

The common carp also serves as a key indicator of environmental health in the river (Weber & Brown, 2009). However, the carp populations are affected by stress factors such as overfishing, habitat degradation, pollution, and increasingly high global temperatures.

In recent decades, climate change has become a critical threat to aquatic ecosystems (Dervis, 2007; Orr et al., 2024), influencing hydrological regimes, water temperatures, and habitat availability. These disturbances significantly impact the life cycles and population dynamics of native species (Seneviratne et al., 2021; Mariu et al., 2023). Due to its wide distribution and ecological relevance, the common carp is an ideal subject for analyzing the effects of climate change on fish population parameters.

The analysis of the sex ratio involves an unbiased sampling for studying the relative abundance of females and males within a population, in our case, the common carp from the Danube River. This analysis provides valuable information about population structure and can be used to assess its health and dynamics.

The Fulton coefficient, also known as the condition factor, is a biometric indicator frequently used to evaluate the health status and overall condition of fish (Mozsar et al., 2014; Morado et al., 2017). It provides essential insights into the nutritional and physiological state of individuals, being particularly valuable for specialists in analyzing how carp cope with critical periods (Latiu et al., 2022; Savin et al., 2022; Thangaraji et al., 2023; Dobrota et al., 2024).

In the scientific literature, there is a significant gap in research addressing the impact of climate change on *C. carpio* populations in the Danube River, particularly concerning parameters such as sex ratio, Fulton condition factor, and size distribution. While general studies on fish fauna exist, detailed longitudinal and regional investigations are lacking to highlight the variability of these indicators under the effects of climatic pressures.

This study aims to fill this gap by providing a perspective on how climate change influences common carp populations in the Danube River. The research focuses on data collected between 2021 and 2024, offering a comprehensive view of *C. carpio* vulnerabilities. The findings emphasize the need to implement sustainable management strategies to mitigate the effects of climate change on freshwater ecosystems.

MATERIALS AND METHODS

Data collection. Was conducted by the research staff of Research and Development Institute for Aquatic Ecology Fishing and Aquaculture of Galati (I.C.D.E.A.P.A. *in Romanian*) during scientific fishing sessions held in all four seasons, between 2021 and 2024 along the entire Romanian section of the Danube River, from Moldova Nouă to Galați (Figure 1).

Fishing was carried out using two types of gear, fixed and drift gillnets. The dimensions of the fishing gears were as follows: for fixed nets, the set length ranged between 100 m and 200 m, the vertical height varied between 2.5 m and 3.5 m, and the mesh size (a) measured between 40 mm and 60 mm (knot to knot). For drift nets, the set length ranged between 150 m and 200 m, the vertical height could vary between 2.5 m and 4.0 m, while the mesh size (a) ranged between 40 mm and 80 mm (knot to knot).

According to Order 342/2008, the legally allowed minimum size for common carp is 40 cm, which justifies the dimensions of the fishing gear used.

Figure 1. Danube River basin – Study area
(Source: www.icpdr.ro)

For each common carp specimen, total length (cm), standard length (cm), and maximum height (cm) were recorded using an ichthyometer with ± 0.01 cm precision. Weight was measured using a scale with ± 0.01 g precision.

Environmental data for 2021-2024 were obtained from the National Institute of Hydrology and Water Management (https://www.hidro.ro/en/bulletin_type/diagnoza-si-prognoza-pentru-dunare/) for all hydrological stations located along the Danube River, and the annual mean values were calculated. The annual variation range was determined by identifying the minimum and maximum values for each year.

Data processing and graphs were performed using the XlStat program and R software version 4.4.2.

Analysis of Length-Class Distribution. The length-class distribution was analyzed to assess the demographic structure and health of the population. Length classes, set at 5 cm intervals (ranging from the minimum to the maximum lengths of captured specimens), were used to group individuals based on their size.

The frequencies for each class were calculated and data validation was performed using the Grubbs Test to identify outliers and the Shapiro-Wilk test to verify the normal distribution of the frequencies per class each year. These validations are essential to ensure that the assumptions of subsequent statistical tests are met. The condition of homogeneous was confirmed through the Bartlett's Test (at a confidence level of 0.05). To evaluate differences between the years 2021-2024, a one-way ANOVA test was applied, comparing frequencies per year and identifying statistically significant differences.

Sex Ratio Analysis. The sex ratio was calculated annually, expressing the number of females relative to the number of males (e.g., 1:1, 2:1).
For statistical analysis, the data distribution was verified using the Shapiro-Wilks test at a 95% significance level, confirming normality for both sexes. According to Berk and Jones (1979) and Pearson (1900), the Chi-squared Goodness-of-Fit test was applied to compare the observed distribution with the expected proportions (Rashid, 2018).

Fulton's Condition Factor. According to Bagenal and Tesch (1978), Fulton's condition factor was calculated annually for each specimen using the formula: $K = 100*TW/TL^b$, where: K is Fulton's condition factor, TW represents total body weight (g), TL is total length (cm) and b represents a value demonstrating fish normal growth dimensions, from the weight-length relationship, expressed as: $TW = a*TL^b$, where intercept (a) describes the rate of change of weight with length and slope (b) gives information about the type of growth (Froese, 2006). The relationships between the weight and the length of fish were determined through linear regression (Log TW = Log a + b*Log TL) (Stavrescu- Beldivan et al., 2022).
A value of b greater than 3 indicate a positive allometric growth pattern, while when b is less than 3 shows a negative or hypoallometric growth pattern (Karachle and Stergiou, 2012).
This condition index is used to compare fish populations from different habitats or to monitor seasonal changes in their condition. A $K>1$ indicates good health and nutrition, while a $K<1$ suggests poor condition, possibly due to environmental issues or limited access to food (Nash et al., 2006; Vishwakarma et al., 2024).
Fulton's condition factor was calculated separately for males and females. This index varies significantly depending on species, habitat, and season, emphasizing the need for contextualized interpretation (Ricker, 1975; Blackwell et al., 2000). Fulton's condition factor is essential for monitoring fish populations in natural environments and aquaculture, providing valuable insights into environmental quality and the trophic dynamics of ecosystems. Statistical analysis for Fulton's Condition Factor for the analyzed period included the Kruskal-Wallis Test, due to non-normal distribution for both genders. The Kruskal-Wallis test is a non-parametric test used to compare the medians of two or more independent groups. The test was chosen to assess whether there are significant differences between distributions of the condition values across annual data (Siegel, 1988; Corder & Foreman, 2009). Post-hoc analysis was conducted using Dunn's test to precisely identify which groups are significantly different and Bonferroni correction was applied to minimize Type I errors (Dunn, 1964; Costa et al., 2015).

RESULTS AND DISCUSSIONS

Between 2021 and 2024, a total of 1956 carp specimens were captured, with a combined weight of 6315.59 kg. The morphological parameters of the catches, broken down by year, are presented in Table 1 (for mean values, standard deviation is provided).

Analysis of Length-Class Distribution
The distribution of individuals across length classes provides information about the demographic structure, the health of the carp population, and environmental conditions, including the impact of climate change, food availability, and spawning habitats (Stavrescu-Bedivan et al., 2015). The presence of multiple length classes indicates a diverse population with good recruitment and survival rates (Jin et al., 2015). The dominance of a single length class may indicate overfishing, increased mortality, or unsuitable environmental conditions, while the absence of certain classes reflects issues with recruitment or survival.

Table 1. Morphometric parameters of the common carp specimens captured during the 2021-2024 period (No. ex.: number of fish sampled; mean ± standard deviation, min., max.).

Specification	No. ex.	TW (kg)	W mean (kg)	W min. (kg)	W max. (kg)	TL mean (cm)	TL min. (cm)	TL max. (cm)
2021	467	2200.20	4.71±2.19	0.80	8.30	66.88±12.55	41.00	90.00
2022	453	1456.33	3.21±1.21	1.00	7.00	56.44±8.14	30.00	80.00
2023	516	1323.33	2.56±1.03	0.50	5.70	54.85±6.99	30.00	71.00
2024	520	1335.73	2.57±1.02	0.50	5.70	54.88±6.98	30.00	71.00

NB. No. ex. - number of fish sampled; mean ± standard deviation; minimum value, maximum value.

Bartlett's Test show homogenous variances (for df=3 and α=0.05 resulted $\widehat{\chi^2}$=7.18<χ^2_{critic}=7.81) for the frequencies in each class between 2021 and 2024, while ANOVA results (for df=3, 48 and α=0.05 $\hat{F}$= 0.057<Fcritic = 2.79) showed no differences between the group means (i.e., the frequencies per class per years 2021-2024). This suggests that, although differences in means and standard deviations were observed, they were not large enough to be statistically significant. However, the observation of the distribution curves (Figure 2) indicates a slightly different patterns in length distribution from 2021 to 2024.

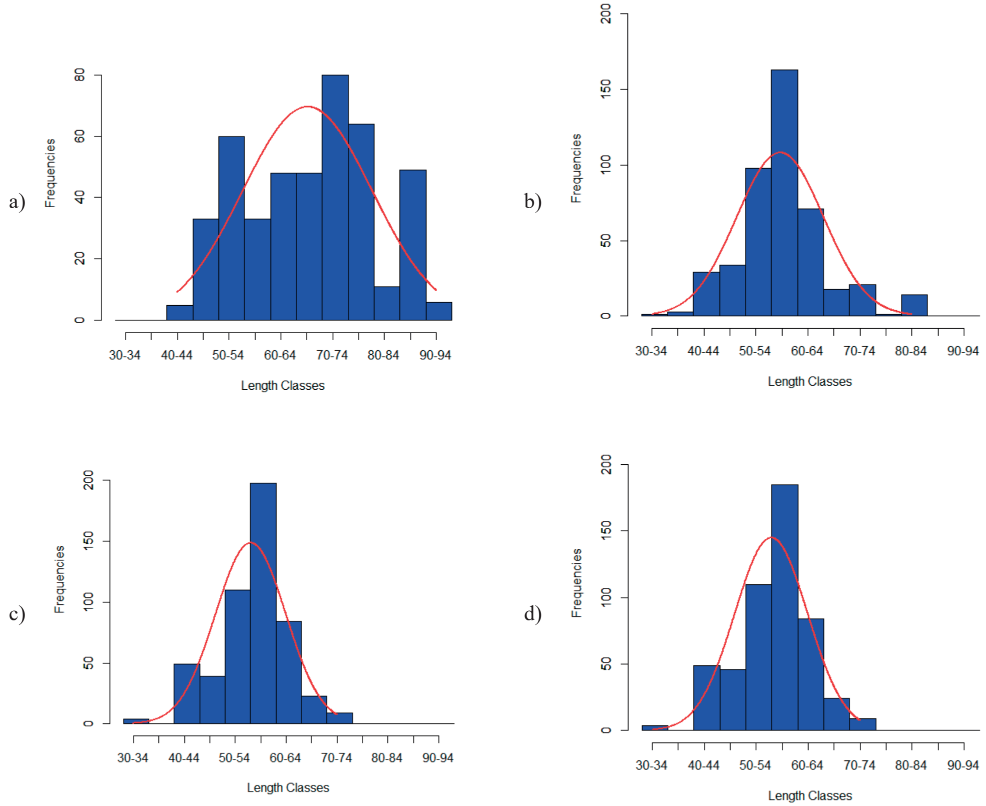

Figure 2. Total Length distribution of common carp population in the Danube River, 2021-2024 period (in cm): a) 2021; b) 2022; c) 2023; d) 2024.

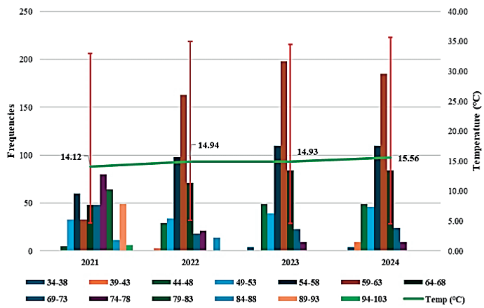

Figure 3. Total Length class distribution and mean annual water temperature

The range of the length distribution recorded in 2021 shows 4 length classes beyond the 70-74 class, we observe 2 in 2022 but none in 2023 and 2024.

Between 2022 and 2024, a significant increase in the number of individuals in the 59-63 cm length class was observed as water temperatures rose, from 33 ind. in 2022 to 163 ind. in 2023, peaking at 198 ind. in 2023 before slightly decreasing to 185 ind. in 2024 (Figure 3).

In 2023, a higher number of specimens was also recorded in the 44-59 cm length classes. However, in 2024, the numbers for the 39 and 44 cm classes remained stable, while those for the larger classes (79, 84, and 89 cm) decreased. Similar trends were reported for the Danube Delta by Stroe et al. (2022).

Overall, there has been a gradual decrease in the number of individuals in the larger length classes, alongside a reduction in the average length of the population, from 66.28 cm in 2021 to 54.40 cm in 2024. Additionally, CV has decreased from a maximum of 18.47% in 2021 and a minimum of 12.74% in 2023, indicating lower variability in the size of individuals, while the slight increase in 2024 to 13.44 may indicate either a diversification of lengths (e.g., the recruitment of younger individuals or the survival of larger ones) or a change in population structure.

Sex Ratio Analysis

The sex ratio (F/M) for the period 2021-2024 indicates a predominance of males. This observation may reflect ecological or biological factors that favour male survival. The results of the Chi-square test (Table 2) show significant deviations from the theoretical balance ratio in the years 2021, 2022, and 2024 ($\hat{X}$-squared>$X_{critical}$). In 2023, the ratio does not differ significantly from equilibrium ($\hat{X}$-squared < $X_{critical}$).

Table 2. Chi-square Test: Comparison of Annual Values

Specification	2021	2022	2023	2024
Chi-squared	9.047	6.20	3.10	8.93
Critical Chi-squared	3.84	3.84	3.84	3.84
p-value	0.030	0.145	0.481	0.066

The evolution of the F/M ratio (Figure 4) shows a trend towards equilibrium in 2023, followed by a slight decrease in 2024, although that does not necessarily indicate a critical population imbalance. Deviations from the 1:1 ratio do not inherently signal a problem but rather reflect natural fluctuations influenced by environmental conditions, fishing pressure, and biological dynamics. In the case of common carp, such variations are common and may be linked to recruitment success, habitat changes, or selective fishing practices, rather than an immediate threat to population stability.

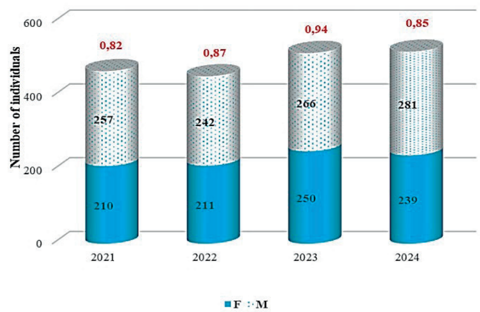

Figure 4. Sex Ratio in common carp population between 2021 and 2024

Previous research has highlighted a masculinization effect in the species, under the effect of elevated temperatures (Biswas et al., 2021), a trend that is also reflected in the F/M ratios obtained in this study.

The values are much higher compared to those recorded in 1996 (Ciolac, 2004) - ranging from 0.42 to 0.65, which suggests either an increase in the proportion of females in the population or a decrease in the number of males.

In the analysis of the relationship between water level and water temperature with the sex ratio, moderate influences of both variables on the sex distribution in the population are observed. A higher water level, as seen in 2023 (437.27 cm), is associated with an increase in the sex ratio, which may indicate a positive effect of favourable environmental conditions on the proportion of males to females. At the same time, water temperature, which ranged between 14.12-15.56°C. Also influences this distribution, impacting fish development and reproduction. Although the relationship is weak (Pearson coefficient = 0.4 between Sex Ratio and water level, respectively, 0.3 for water temperature), these environmental conditions may play a significant role in determining sex ratios, influencing reproductive success and the overall development of the population (Geffroy & Wedekind, 2020).

Fulton's Condition Factor

The Kruskal-Wallis test result revealed significant differences across the annual values of K for both females ($p<0.05$ and $\chi^2 = 741.59 > \chi^2$_critical = 7.81, with df = 3 and $\alpha = 0.05$) and males ($p<0.05$ and $\chi^2 = 900.4 > \chi^2$_critical = 7.81, with df = 3 and $\alpha = 0.05$) (Figure 5a). The Dunn test for the female individuals, adjusted with the Bonferroni correction, showed pronounced contrasts between 2022-2024 ($Z = 24.51$, p.adj $\approx 7.71 \times 10^{-132}$) and 2021-2024 ($Z = 20.11$, p.adj $\approx 3.85 \times 10^{-89}$).

A similar pattern was observed also for males, where the Dunn test, also adjusted using the Bonferroni correction, confirmed significant differences across all years. The highest Z value was recorded for the 2021-2024 comparison ($Z = 27.59$, p.adj $\approx 9.99^{-167}$), although all other comparisons also yielded equally significant results (Figure 5b).

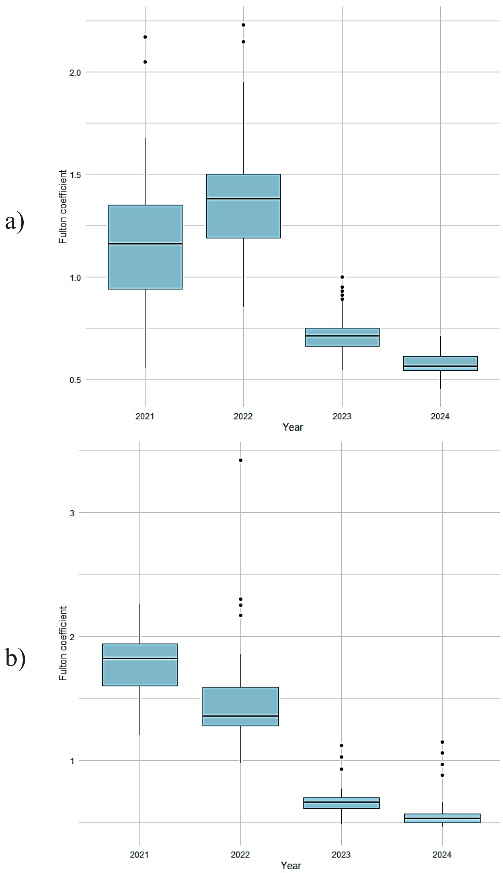

Figure 5. Fulton's Condition Factor.
Annual values distribution between 2021 and 2024:
a) Females; b) Males

Table 3. Fulton's Condition Factor

Specification	Females					Males				
Years	Kmin.	Kmax.	Kmean	a	b	Kmin.	Kmax.	Kmean	a	b
2021	0.54	2.17	1.16±0.25	0.0113	3.0524	1.2	2.26	1.78±0.22	0.0177	2.9430
2022	0.85	2.23	1.36±0.23	0.0135	3.0324	0.98	3.42	1.42±0.24	0.0141	3.0234
2023	0.43	0.80	0.56±0.06	0.0056	3.2475	0.48	1.12	0.65±0.08	0.0054	3.2011
2024	0.44	0.71	0.58±0.05	0.053	3.2532	0.46	1.47	0.54±0.07	0.0054	3.2181

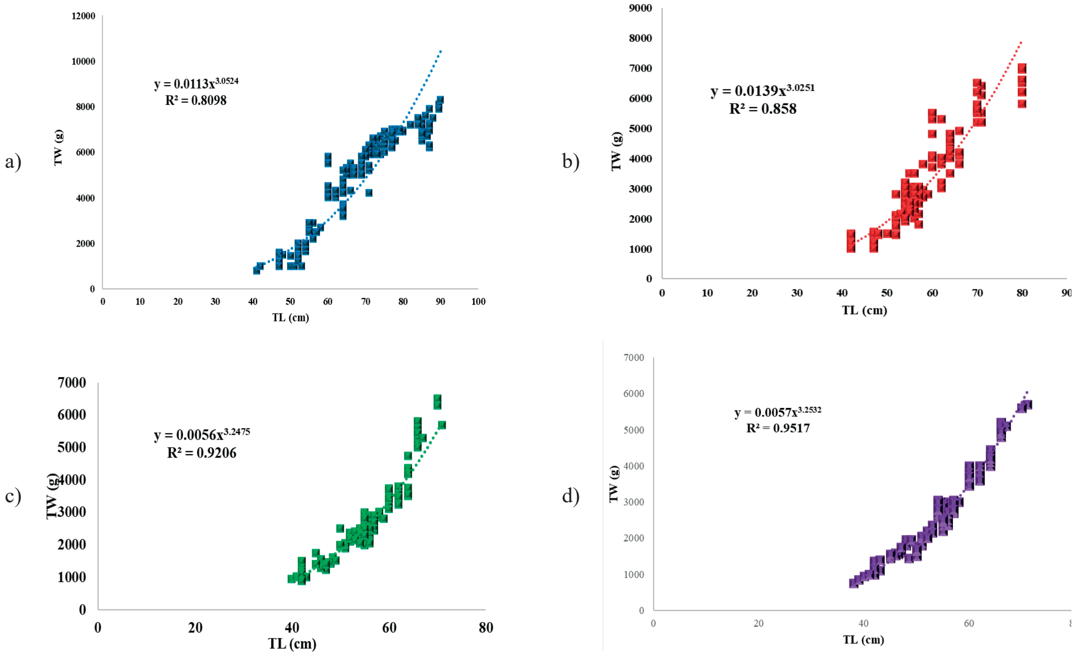

Figure 6. Weight-Length Relationship for carp female: a) 2021; b) 2022; c) 2023; d) 2024

For female, the annual WLRs were expressed as:
Log (TW) = 10864* log (TL) – 40791; TW = 0.0113* $TL^{3.0524}$ with r^2 =0.81 (confidence level of 95% for the intercept and slope) - 2021 (Figure 6a).
Log (TW) = 9527.1* log (TL) – 35359; TW = 0.0135* $TL^{3.0324}$ with r^2 =0.86 (confidence level of 95% for the intercept and slope) - 2022 (Figure 6b).
Log (TW) = 8003* log (TL) – 29360; TW = 0.056* $TL^{3.2475}$ with r^2 =0.92 (confidence level of 95% for the intercept and slope) - 2023 (Figure 6c).
Log (TW) = 7826.3*log (TL) - 28540; TW = 0.0057* $TL^{3.2532}$ with r^2 =0.87 (confidence level of 95% for the intercept and slope) - 2024 (Figure 6d).
Growth type for female carp caught between 2021 and 2024 showed a positive allometric pattern, with b > 3 for each year, suggesting that the fish biomass increases faster than length, so the organism becomes more robust or stocky, while the strong r^2 shows a strong correlation between biomass and length.

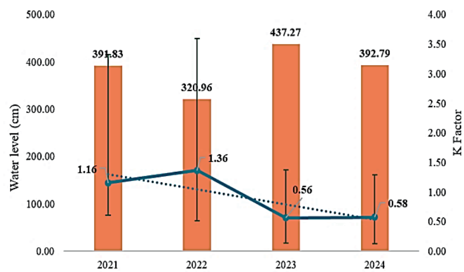

Figure 7. Evolution of K factor (female values) in correlation with Danube's annual mean water level between 2021 and 2024

The annual average values of female K for 2021-2024 range between 0.56 in 2023 and 1.36 in 2022. The variations are shown in Table 3 and Figure 7, suggesting that the Fulton factor was good in 2021-2022, but dropped sharply in 2023, with no clear signs of recovery in 2024. Combined with the decrease in the error bars, this trend indicates a general and uniform deterioration in fish condition, not only for a few individuals, but for the whole population.
This indicates a possible deterioration of environmental conditions or other negative ecological changes.

A Pearson coefficient of -0.82 between K and water level suggests a strong negative correlation, meaning that as the water level increases, the Fulton's condition factor (K) tends to decrease. This implies that higher water levels may negatively impact the overall condition of the fish, possibly due to factors such as changes in food availability, habitat alteration, or increased energy expenditure required for movement and foraging.

For male individuals, the annual WLRs were expressed as:

Log (TW) = 10556* log (TL) – 39625; TW = 0.0177* $TL^{2.943}$ with r^2 =0.94 (confidence level of 95% for the intercept and slope) - 2021 (Figure 8a).

Log (TW) = 8517.5* log (TL) – 31271; TW = 0.0141* $TL^{3.0234}$ with r^2 =0.92 (confidence level of 95% for the intercept and slope) - 2022 (Figure 8b).

Log (TW) = 6683.6* log (TL) – 24118; TW = 0.0054* $TL^{3.2011}$ with r^2 =0.96 (confidence level of 95% for the intercept and slope) - 2023 (Figure 8c).

Log (TW) = 6577.1*log (TL) - 23964; TW = 0.0054* $TL^{3.2181}$ with r^2 =0.97 (confidence level of 95% for the intercept and slope) - 2024 (Figure 8d).

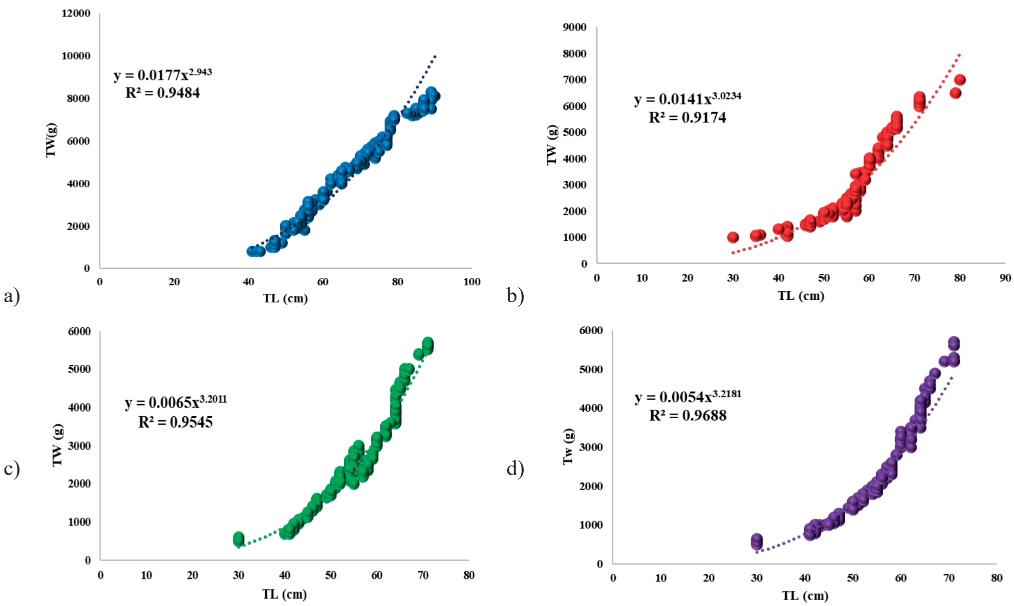

Figure 8. Weight-Length Relationship for carp male: a) 2021; b) 2022; c) 2023; d) 2024

Between 2021 and 2024, the growth type of male carp varied from a hypoallometric type in 2021 (with b < 3), suggesting that growth in length was proportionally greater than weight gain, to a positive allometric growth from 2022 on, indicating improved conditions and a more balanced energy allocation towards body mass accumulation.

The annual average value of male K ranged from 0.54 in 2024 to 1.78 in 2021 (Table 3, Figure 9), underlining the same decline as in female carp population, which suggests a consistent downward trend in body condition over the years.

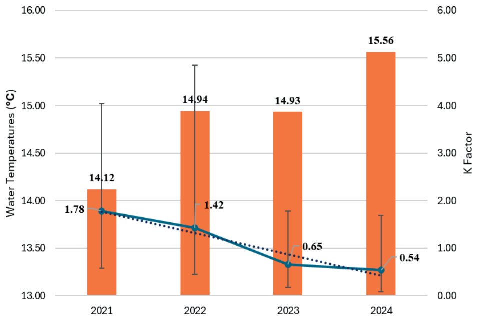

Figure 9. Evolution of K factor (male values) in correlation with Danube's water annual mean temperatures between 2021 and 2024

With a strong negative correlation of -0.85, the male K factor is influenced by water temperature, meaning that as the water temperature increases, the Fulton's condition factor (K) tends to decrease. Chezik et al. (2014) utilized maximum and minimum air temperature values, or the number of days above a certain threshold, to demonstrate the impact of climate change on aquatic ecosystems. This study explores the annual variation in water temperature between 2021 and 2024 and examines how these fluctuations influence the variation in the Fulton's condition factor (K), providing further insights into the relationship between climate dynamics and fish health in the Danube River.

A negative allometric growth in carp and a good condition of 1.98 (with no gender separation), was recorded also by Stavrescu-Beldivan et al. (2022) for the population Pond Bitina 3 in Ialomita County.

The differences between the values reported by Ciolac (2000) and the current ones could indicate an improvement in the condition of carp over the past decades. However, the downward trend observed in 2023-2024 and the negative correlation with water level and water temperature suggest a recent decline in fish condition, which could be linked to ecological or anthropogenic factors. As Lenhardt et al., 2012 and Milanov et al., 2016 sustained environmental factors, such as pollutants, especially heavy metals, have a significant negative impact on fish health and contribute to a decrease in Fulton's condition factor. The accumulation of these pollutants in the tissues of *C. carpio* can cause physiological stress, which is reflected in slowed growth and deteriorating physical condition (Milanov et al., 2016).

The improvements in 2022 and 2023 may reflect a positive adaptation to environmental conditions, physiological response to the shifting environment, but the decline in 2023-2024 could be a warning signal to be considered in the future, related to climate change, pollution, or other ecological pressures. The differences between the minimum and maximum values remain significant, highlighting the presence of individuals in both excellent and poor conditions.

Compared to other regions, the values obtained for *C. carpio* in the Danube are much lower than those reported by Zencir Tanir (2020) in Tercan Dam Lake, Eastern Anatolia, Turkey (2.148±0.030), and those reported by Daliri (2012) for the Caspian Sea (1.34±0.24). Also, in Lake Naivasha, Kenya in 2013-2014, the K factor was greater than 1 for both female and males as observed by Aera et al. (2014).

CONCLUSIONS

A gradual decrease in the average size of individuals was observed during the period 2021-2024, which may reflect both ecological pressures and the effects of climate change. The length class distribution indicates a reduction in the number of large individuals, signaling the possibility of overexploitation or other stress factors. The F/M ratio showed a tendency towards equilibrium during the analyzed period, increasing from 0.82 in 2021 to 0.94 in 2023, but with a slight decrease in 2024 (0.85). This fluctuating equilibrium could influence the reproductive success of the population.

The K factor was higher in 2021-2022 but experienced a sharp decline in 2023, with no clear signs of recovery in 2024, suggesting a general deterioration in the fish population's condition rather than affecting only isolated individuals. In females, K showed a strong negative correlation (-0.82) with water levels, indicating that higher water levels may negatively impact body condition, while in males, K exhibited an even stronger negative correlation (-0.85) with water temperature, suggesting that higher temperatures could adversely affect growth and overall condition. Regarding growth patterns, females consistently maintained positive allometric growth (b>3) throughout the years, indicating a faster accumulation of body mass relative to length, whereas males transitioned from hypoallometric growth in 2021 (b<3, indicating greater length growth than weight gain) to positive allometric growth starting in 2022, reflecting a temporary improvement in conditions. However, the significant decline in the K factor in 2023-2024 may serve as a warning sign of the impact of climate change, pollution, or other ecological pressures on the aquatic ecosystem, contributing to stress on the common carp population, reflected in variations in population structure and individual condition. However, it is necessary to further analyze to what extent these factors have influenced the carp population.

The reductions in size and body condition in 2024 underline the urgency of adopting adaptive measures to conserve the *C. carpio* populations and protect the Danube ecosystem.

This study provides an integrated perspective on the impact of climate change on key parameters of the common carp population in the Danube River, highlighting the need for science-based management to ensure the resilience of this species.

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