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OVERALL EFFECTS OF CLIMATE CHANGE ON ECONOMICALLY VALUABLE FISH POPULATIONS IN THE DANUBE RIVER

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Abstract

The ecosystems of the Danube River basin exhibit remarkable biodiversity, housing over 2,000 plant species and more than 5,000 animal species. This places the Danube among Europe's most valuable rivers in terms of aquatic life diversity, with a total of 103 identified species. The Danube is increasingly affected by climate change, impacting the hydrologic cycle and the availability of food and water resources. The effects of climate change are already observable and projected to intensify, notably in increased frequency and intensity of extreme weather events such as heatwaves, drought periods, and floods. In this paper, we aim to present the impact of climate change on economically valuable fish within the Danube River. We have determined the abundance of these species and analyzed the correlation between recorded temperatures and the river's water level. Given the Danube's unique variety of species, we will highlight the importance of protecting and conserving this valuable ecosystem amidst the escalating climate threats.

Key words: *abundance, aquatic ecosystems, carp population, environmental factors, predatory species.*

INTRODUCTION

Global climate change is one of the greatest challenges of the 21st century (Sarwar, 2008), with significant implications for aquatic ecosystems and fishing resources worldwide (Hoegh-Guldberg & Bruno, 2010). Such climate alterations have a negative impact on fish migrations and habitats, leading to increases in fish abundance in certain areas and decreases in others (Hannesson, 2007).

According to Aadland (1993), river level and water temperature, as well as their modifications, are key variables influencing fish species' habitats and behavior. The natural diversity of fish communities can be explained by variations in water level, water temperature, physical habitat, water quality, and other significant environmental characteristics (Poff & Allen, 1995; Gebrekiros, 2016).

The effect of temperature on fish species distribution has long been recognized, manifesting at a broad geographic scale (Shuter, 1980). Temperature changes can lead to increased physiological demands and stress, reduced water oxygen saturation levels (Byrne, 2011; Matthews & Berg, 1997), limit fish species distribution, and alter their biological cycles, behavior, and distribution.

The interaction between temperature and precipitations is one of the key factors influencing the hydrological cycle within a watershed. Temperature and precipitation changes, caused by climate change, become essential elements for the transformation of the hydrological cycle. In the case of the Danube River, the hydrological regime is influenced by its geographical location on the continent at the intersection of the temperate-oceanic climate in the west, the temperate-continental climate in the east, and Baltic influences in the north (Chioveanu et al., 2020; Stroe et al., 2023). The evolution of water temperature is shaped by the distinct characteristics of the traversed regions.

Water temperature represents a central parameter in determining the overall health status of aquatic ecosystems, considering that aquatic organisms have specific temperature ranges they can tolerate. Additionally, air temperature significantly influences water temperature, as water warms and cools more slowly than air, generating linear variations in water temperature compared to abrupt changes in air temperature.

Water level represents a measure of the water height in a body of water, such as a river, a lake, or an ocean, relative to a certain reference point (Scrădeanu & Gheorghe, 2007). The Danube River level is a crucial parameter, holding major implications for fish habitat. The variability in water level can affect the availability of breeding and feeding areas for fish species.

In these conditions, aquatic ecosystems are subject to increasing pressure, and the Danube River, Romania's main hydrological artery, is no exception. The Romanian region of the Danube River holds special significance for fish populations, essentially constituting a central wetland area (Ibănescu et al., 2016). The Danube Basin region encompasses a fascinating diversity of ecological territories, providing shelter for numerous plants and animals with unique characteristics.

The lower segment of the Danube River covers a distance of 1072 km, representing 38% of its entire length, from the Iron Gates to its mouth in the Black Sea. Over time, the Danube's ichtyofauna has undergone profound changes determined by embankments and hydrotechnical works, water pollution, increases in fishing effort, as well as improvements in fishing methods and tools. Research on the Romanian sector's ichthyofauna of the Danube has led to the identification of 66 fish species, systematically classified into 19 families (Bacalbașa et al., 1984).

The fishery resource supporting the fishing activity is ensured by a small number of fish species. Thus, even though the Danube's ichtyofauna includes 66 species, mostly freshwater fish or migratory species, only 18 species are commercially fished. The main economically valuable fish species caught annually are: pontic shad, perch, catfish, carp, pike. These species represent not only important resources for the fishing industry but also sensitive indicators to environmental changes. Understanding fish population dynamics and processes, including recruitment, growth and mortality is fundamental for improving fish stock evaluation and more efficient fisheries management (Sparre & Venema, 1998). Furthermore, Pauly (1983) considered that growth parameters and mortality rates represent key aspects of fish stock assessment. This importance derives from their ability to provide crucial information about how fish size varies over time and about the reduction in populations due to fishing and/or natural factors.

This paper focuses on exploring trends recorded by environmental factors (water level and temperature) during the period 2018-2022, highlighting the fluctuation and significant changes that can directly influence the annual catches of economically valuable fish species, as well as the total allowable catch, to provide a clear imagine of fishing sustainability and how climate change can affect the population of these species.

Additionally, the paper analyzes whether there are significant discrepancies between reported catches and allowable limits, identifying potential pressures on these exploited fish populations. This analysis will contribute to formulating recommendations for more efficient and sustainable resource management, considering climate change and its impact on economic species.

Through a holistic approach, we aim to contribute to a detailed understanding of complex interactions between climate changes, environmental factors and the exploitation status of valued species in the Danube River, thus providing a useful framework for decision-making in the sustainable management of aquatic resources.

MATERIALS AND METHODS

Data collection. The analysis of the influence of environmental factors was based on processing information regarding the daily water levels and temperatures of the Danube River from the period 2018 to 2022, obtained from the National Institute of Hydrology and Water Management (I.N.H.G.A.). Moldova Veche - km 1048, Calafat - km 795, Giurgiu - km 493, Braila - km 170, and Tulcea - km 71 were established as reference stations. Their processing involved calculating the annual average values for each analyzed station.

The comparative analysis of reported fish catches for the period 2018-2022 was conducted based on official data obtained from the National Agency for Fisheries and

Aquaculture, for the Romanian sector of the Danube, from the entry into the country at Baziaș to the Black Sea. The data were statistically processed using the Excel program from the Office 365 package.

Fishing area. The fish samples subjected to analysis were collected by research personnel from the Research and Development Institute for Aquatic Ecology, Fishing and Aquaculture Galați at the five mentioned stations (Figure 1), during scientific fishing sessions from May to August each year during the period 2018 to 2022.

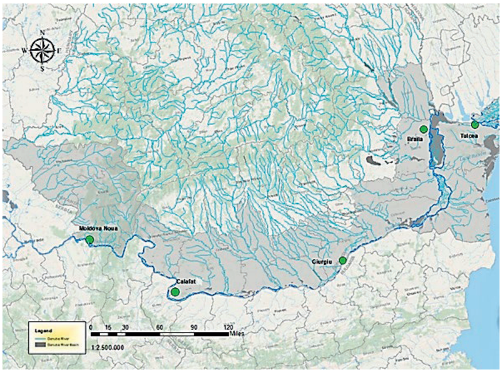

Figure 1. Fishing area in Danube River Basin km 71-km 1048, Romania (Source: original map)

Fishing was carried out using gear such as fixed nets and floating nets. The dimensions of the fishing gear were as follows: For fixed nets, the length of the set (Lp) ranged from 100 to 200 m, the vertical height (Hp) varied between 2.5 and 3.5 m, and the mesh size (a) measured between 40 and 60 mm.

In the case of floating nets, the length of the set (Lp) ranged from 150 to 200 m, the vertical height (Hp) could be between 2.5 and 4.0 m, while the mesh size (a) varied between 40 and 80 mm.

Utilizing an ichthyometer with a precision of ±0.01 cm, we gathered precise data on the total length (cm), standard length (cm), and height (cm) of the fish specimens.The weight of the specimens was determined with high precision using a scale with an accuracy of ±0.001 g.

The growth parameters and mortality rates. Growth parameters were estimated using the von Bertalanffy growth function (VBGF) (Von Bertalanffy, 1938) within the FISAT II program, using length-frequency data (class interval of 5 cm).

The specimens captured from the Danube River were grouped into length classes of 5 cm, and for each year of the analyzed period, the asymptotic length ($L\infty$; cm), growth coefficient (k; $year^{-1}$), and growth performance index (ϕ') were calculated.

According to Santos et al (2022), the asymptotic length represents the length that fish in a population would reach if they were to grow indefinitely, and k is the growth coefficient that expresses the rate at which the asymptotic length is approached.

The growth performance index (Ø') is a measure of the efficiency of individual fish growth, calculated using the formula $Ø' = \log_{10}(K) + 2*\log_{10}(L\infty)$ (Munro & Pauly, 1983).

Data regarding the length of the harvested biological material were separated by sexes, but growth parameters were estimated for both sexes. The purpose of estimating growth parameters is to gain a deeper understanding of how individual organisms or populations grow in size or weight depending on factors such as environmental conditions and food resource availability. These estimates can provide valuable information for assessing the health and stability of ecosystems and anticipating the impact of environmental changes on biodiversity.

The total annual mortality rate (Z; $year^{-1}$) for economically valuable species captured was estimated using length-based catch curves (Ricker, 1975) in FISAT II.

Natural mortality (M; $year^{-1}$) was calculated based on Pauly's empirical formula (Pauly, 1980), while fishing mortality (F; $year^{-1}$) was obtained from the relationship: $F=Z-M$ (Gulland, J.A., 1971). The annual average water temperature (T) was set at 15°C, based on the average annual water temperature of the Danube River.

The exploitation rate of the species was obtained based on the relationship $E=F/Z$ and reflects the degree of fishing exploitation of these species. Estimating mortality rates aims to quantify and understand the impact of factors leading to the death of individuals or populations within a certain time interval.

The growth parameters of fish population dynamics (asymptotic length L∞ and growth coefficient k) are critical for stock assessment and fisheries management (Santos, 2022).

RESULTS AND DISCUSSIONS

In recent years, the intensification of the drought phenomenon, closely linked to the increased frequency of extreme temperatures during the summer and the reduction in precipitation level has a negative impact on our territory, with significant repercussions, especially in the southern and southeastern regions of the country.

The time interval from 2018 to 2020, characterized by precipitation deficits, marked the onset of prolonged drought in Romania. At the same time, the period between 2019 and 2029 stands out as the warmest in the last 11 consecutive years, which is confirmed by the sustained increase in air temperature in our country.

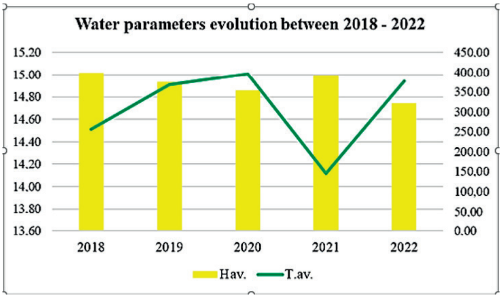

Figure 2. Evolution of Danube parameters 2018–2022 (Source: original)

The analysis of the relationship between the average annual water temperatures and the water level of the Danube River over the past five years indicates an inversely proportional relationship with reciprocal influences (Figure 2). For example, the increase in water temperatures in 2020 and 2022 affects the hydrological regime, resulting in a decrease in the river's water level. The variability of these parameters affects aquatic ecosystems, navigation, and the management of water resources for various uses. Changes in water temperature influence the biological cycles of aquatic species and affect water quality, with a direct impact on biodiversity and even human health. Current research by Madeira et al. (2016) and Linderholm et al. (2014) present the vulnerability of early life stages of aquatic organisms to increases in water temperature.

Thus, a fluctuation in average annual temperature and average annual water level can be observed over the analyzed period. The variation in average annual water temperature of the Danube River ranges from 14.12°C in 2021 to 15.01°C in 2020, with a standard deviation of 0.37°C. Additionally, the average annual temperature varies relatively easily from year to year, ranging from 13.98°C in Calafat in 2021 to 15.72°C in Giurgiu in 2020.

The values of the average annual water level vary on average by 3.43 cm within the interval of Hmin=320.96 cm in 2022 and Hmax=398.14 cm in 2018. Extrapolating the results from the period 2018-2022 to the analyzed stations (Figure 3), it can be observed that each station, except Moldova Veche, whose level remains relatively constant, records significant increases in the average level. The average values range from 71.66 cm at the Giurgiu hydrological station in 2022 to 748.73 cm at Moldova Veche, also in 2022, highlighting the repercussions of the 2022 pedological drought.

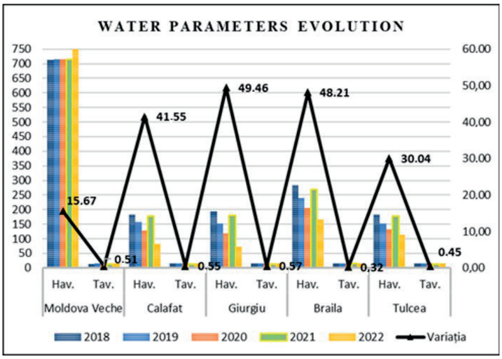

Figura 3. Danube River paramaters variation - on hydrological stations - between 2018-2022 (Source: original)

According to the National Meteorological Administration, the year 2022 - ranked third among the hottest years in Romania and tenth among the driest years in terms of precipitation - was highlighted as a year with pedological drought, caused by low water levels and high temperatures, affecting the availability of food and spawning grounds for fish species.

Analyzing the parameters for each month (Figure 4), it can be concluded that the warmest **January** was recorded in 2021, with high temperatures at all five analyzed stations (T.max = 4.52°C ± 0.79°C). The coldest January was in 2019 (Tmin. = 2.35°C ± 0.79°C). The highest water level was recorded in 2018 (Hmax. = 414.07 cm ± 78.71 cm), while the lowest was in 2020 (Hmin. = 229.79 cm ± 78.71 cm), due to the low precipitation level in that month (January 2020 ranks 3rd in the list of the driest January months).

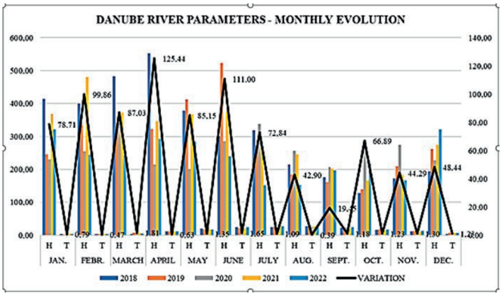

Figure 4. Danube River paramaters variation between 2018-2022 (monthly mean values) (Source: original)

Throughout the period 2018-2022, the relationship between the two parameters was strongly positive (Pearson's coefficient = 0.81).

For **February**, the water level ranged from Hmin = 244.25 cm ± 99.86 cm in February 2022 to Hmax = 480.94 cm ± 99.86 cm in February 2021. The temperature range of the Danube for February is between Tmin = 3.67°C ± 0.47°C (in 2022) and Tmax = 4.90°C ± 0.47°C (in 2020). Throughout the period 2018 - 2022, the correlation between the two parameters was positive (Pearson's coefficient = 0.69).

The warmest **March** in terms of Danube water temperatures was recorded in 2020 with Tmax = 8.11°C ± 181°C, while the coldest was in 2018 (Tmin = 3.80°C ± 1.81°C). Water temperature is one of the central parameters determining the overall health of aquatic ecosystems because aquatic organisms have specific temperature ranges they can tolerate, and variations of nearly 2°C from year to year have negative consequences on populations. The water level in this month ranged from Hmin = 243.20 cm ± 87.03 cm in 2022 to Hmax = 482.92 cm ± 87.03 cm in 2018. The Pearson coefficient value for March<0.5 indicates a lack of correlation between the two parameters.

The water level of the Danube in **April** fluctuated greatly from one year to another, with differences of 125.44 cm compared to the mean values for this month. The boundaries of the water level interval were Hmin = 215.23 cm (in 2020) and Hmax = 552.05 cm in 2018. The minimum level recorded in 2020 was due to extremely low precipitation in that month (the monthly precipitation amount for April 2020 was 12.8 mm, a deviation of -73% from the median of the 1991 - 2020 reference interval). Also, the lowest water temperature recorded during the analyzed period was Tmin = 10.43°C ± 0.63°C. The highest water temperature in April was recorded in 2019, Tmax = 12.03°C ± 0.63°C. The Pearson coefficient = 0.64 highlights the existence of a positive correlation.

In **May**, Tmin = 16.74°C ± 0.63°C, and Tmax = 20.27°C ± 0.63°C, mainly due to high air temperatures (according to the National Meteorological Administration, May 2018 ranks 2nd in the list of the hottest Mays in Romania, from 1961 to 2022). The water level ranged from Hmin = 201.46 cm ± 85.15 cm in 2020 to Hmax = 412.34 cm ± 85.15 cm in 2014. A strong positive correlation between the parameters is highlighted in this month as well (Pearson's coefficient = 0.77).

The water temperature in **June** ranged between 20.49°C and 24.51°C, with fluctuations of 1.65°C from year to year compared to the mean values for this month. The highest water level recorded in June was in 2019, Hmax = 523.20 cm ± 111 cm, and the lowest was in 2020, Hmin = 286.03 cm ± 111 cm. A positive correlation between the parameters is also evident for this month (Pearson's coefficient = 0.62).

July stands out as the hottest month of the year. In July, the Danube's water level ranged from Hmin = 151.07 cm ± 72.84 cm in 2022 to Hmax = 338.16 cm ± 72.84 cm in 2020. The average temperature values range from Tmin = 24.79°C ± 1.09°C in 2020 to Tmax = 27.08°C ± 1.09°C in 2021. There is a strongly positive correlation between the parameters (Pearson's coefficient = 0.73).

The water level in **August** reaches lows of 152.70 cm ± 42.90 cm (in 2023) and highs of 256.23 cm ± 42.90 cm (in 2020), while the temperature ranges between Tmin = 26.21°C ± 0.39°C (2020) and Tmax = 27.24°C ± 0.39°C (2022). A Pearson coefficient value of 0.86 indicates a strong positive correlation between the two parameters.

A strong positive correlation is also evident in **September**, with a Pearson coefficient of 0.96. The temperature range is between Tmin = 21.03°C ± 1.18°C (2020) and Tmax = 23.90°C ± 1.18°C (2022), while the water level ranges from Hmin = 160.65 cm ± 19.45 cm (2019) to Hmax = 206.61 cm ± 19.45 cm (2020).

In **October**, the monthly average for the Danube's water level ranged from 127.71 cm ± 66.89 cm (in 2018) to 290.70 cm ± 66.89 cm (in 2020). The minimum water temperature was recorded in 2021, Tmin = 14.60°C ± 1.23°C, while the maximum was 17.63°C ± 1.23°C in 2019. Pearson's coefficient = 0.67.

In **November**, Tmin = 10.49°C ± 1.30°C (2020), Tmax = 13.36°C ± 1.30°C (2019). Hmin = 167.12 cm ± 44.29 cm (2022), Hmax = 275.01 cm ± 44.29 cm (2020). Pearson's coefficient = 0.76.

In **December**, Tmin = 3.93°C ± 1.23°C (2018), Tmax = 7.27°C ± 1.23°C (2019). Hmin = 193.88 cm ± 48.44 cm (2018), Hmax = 321.70 cm ± 48.44 cm (2022). Pearson's coefficient = 0.94.

Monthly analysis of the Danube's parameters has shown high Pearson coefficient values in the majority of the months, with strong positive correlations in January, August, September, and December >0.8, highlighting the close relationship between the two parameters in these months and the significant influence they exert.

As ectothermic organisms (Favero et al, 2022), for reproduction (Donelson et al., 2010; Pankhurst & King, 2010), growth (Viadero, 2005; Akhtar et al., 2013), and even for survival, most fish species require specific ranges of water temperature and level (Fernandes et al., 2018; de Barros et al., 2019). Large year-to-year differences in both water temperature and level negatively impact river fish populations.

Comparative analysis of TAC and reported catches

Fisheries management is a strategic and practical approach for sustainably managing fish resources, ensuring the conservation of fish species and maintaining the ecological balance of aquatic ecosystems (Lopes, 2021). This field involves the implementation of policies and practices aimed to prevent the overexploitation of fish resources and promoting their sustainable use.

Constant monitoring of fish populations is essential to understand their dynamics. This process involves collecting data on population size. Based on stock assessments, authorities can establish fishing quotas that limit the quantity of fish that can be harvested from a particular area or for a certain species in decline. These quotas are set to prevent overexploitation and to maintain sustainable exploitation of resources.

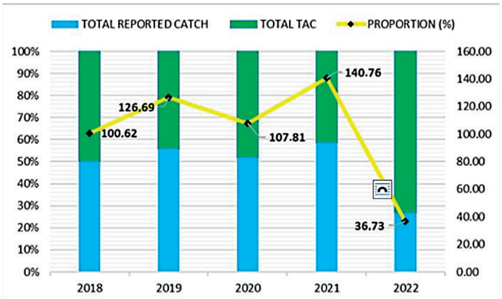

Figure 5. Analysis of Total Allowable Capture vs. Reported Catch (Source: original)

From Figure 5, it can be observed that the reported catch varied from year to year during the analyzed period. The lowest reported catch was in the year 2022 – 160.75 t, indicating either possible changes or limitations in fishing dynamics or resource management policies, or decreases in the migration behavior of aquatic species due to environmental factors.

Throughout the analyzed period, the reported catch exceeded the allowable quota, except in 2022, when the reported values were 36.73% of the Total Allowable Catch (TAC). Exceeding the allowable quotas by over 20% (in the years 2019, 2021) indicates overexploitation of fish populations, which can be concerning from a sustainable management perspective.

Analysis of the status of economically valuable species exploitation

The total of economically valuable species captured in the lower sector of the Danube River during the period 2019-2023 reached a count of 3,608 specimens. The most productive year of scientific fishing was in 2021, with a total of 831 specimens, including 467 carp, 105 perch, 200 catfish, and 59 pike. This was a year in which the analyzed environmental parameters, the temperature and water level of the Danube River (Tav. = 14.12°C and Hav. = 391.83 cm), favored the development of breeding and feeding habitats.

The proportion of each species and their distribution by gender is depicted in Figure 6, revealing a slightly higher presence of male specimens in the catches each year.

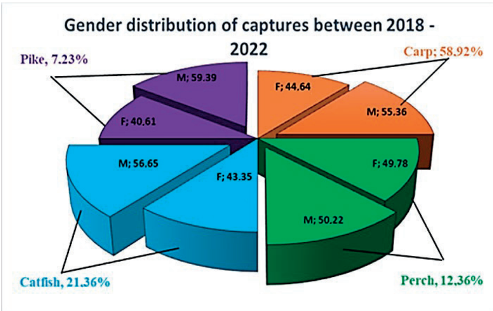

Figure 6. Gender distribution of captures between 2018-2022 (Source: original)

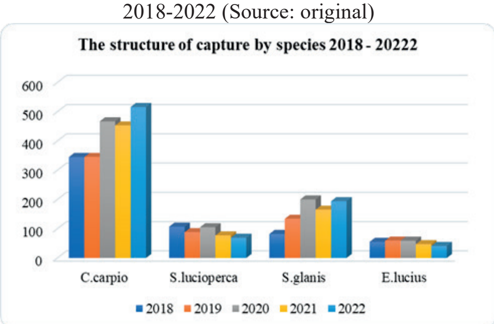

Figure 7. The structure of capture by species between 2018-2022 (Source: original)

From Figure 6 and Figure 7, the dominant presence of the carp species can be observed each year, accounting for 58.92%, followed by catfish with 21.48%, perch with 12.36%, and pike with 7.23%. The dominance of carp in the catches each year indicates that the fishing area provides specific breeding and feeding habitats for peaceful species. Additionally, years with high water levels, such as 2018 and 2021, favor the growth of aquatic vegetation, which provides suitable spawning substrates for phytophilic and phytofilic cyprinids, such as carp, etc. (Janac et al., 2010).

On the other hand, catfish and perch species occupy secondary positions, with percentages of 21.48% and 12.36%, respectively, indicating a significant but lesser presence compared to carp. The increase in water temperature may be conducive to predatory fish species such as catfish, perch, and pike by stimulating the growth rate of juveniles, increasing individual metabolic rates, and extending the growing season (Szczepkowski, 2006; Winfield et al., 2008). However, Hassler, 1982 reported for the northern pike that in the case of eggs incubated at temperatures higher than 15°C, premature hatching may occur, leading to anomalies in larvae that hinder the functional development of yolk sac larvae, adherence, and sinking to the bottom of the water, where toxic conditions are often encountered (low oxygen levels, presence of hydrogen sulfide). This phenomenon could increase larval mortality by 40%.

The pike species recorded the lowest presence, representing only 7.23% of the total catches, suggesting a more limited presence but indicating an ecosystem balance.

From year to year, a decrease in the size range of individuals can be observed, from 35-91 cm (Lt) in 2019 to 30-71 cm in 2023 (Table 1), which may indicate a change in the demographic structure of the fish population or may result from external influences, such as or changes in the aquatic habitat. Within the same species, variations in the parameters L∞ and k can be attributed to a wide range of causes, including changes in water conditions, food availability, metabolic rate, fishing pressure, and pollution levels.

Additionally, the growth performance indices (ϕ') of carp, perch, and pike vary significantly over time and may reflect changes in growth rates and estimated maximum length of the analyzed fish species, while for catfish, it remains relatively stable.

Table 1. Parameters of the von Bertalanffy growth equation for catches from the period 2019–2023

SPECIES	NO. OF FISH	LTMIN.	LT.MAX	L∞	K	M	Z	F	E	M/K	Φ'
CYPRINUS CARPIO											
2019	345	35	91	94.5	0.91	0.91	1.07	0.16	0.15	1.00	3.91
2020	345	35	91	94.5	1.2	1.09	0.37	-0.72	-1.96	0.91	4.03
2021	467	41	90	94.5	0.45	0.58	1.34	0.76	0.57	1.29	3.60
2022	453	30	80	84	1.5	1.31	1.71	0.4	0.24	0.87	4.02
2023	516	30	71	73.5	0.61	0.75	1.67	0.92	0.55	1.23	3.52
TOTAL	2126										
SILURUS GLANIS											
2019	82	52	91	94.5	0.56	0.66	0.64	-0.02	-0.04	1.18	3.70
2020	134	56	98	99.75	0.62	0.7	1.82	1.12	0.62	1.13	3.79
2021	200	45	90	94.5	0.56	0.66	0.85	0.19	0.22	1.18	3.70
2022	165	38	92	99.75	0.62	0.7	1.91	1.21	0.63	1.13	3.79
2023	194	30	91	94.5	0.56	0.66	0.97	0.31	0.32	1.18	3.70
TOTAL	775										
SANDER LUCIOPERCA											
2019	107	28	57	57.75	1.4	1.39	2.91	1.52	0.52	0.99	3.67
2020	88	28	57	57.75	1.4	1.48	3.95	2.56	0.65	1.06	3.67
2021	105	28	63	63	0.89	1.01	1.24	0.23	0.19	1.13	3.55
2022	77	28	50	52.5	1.1	1.22	5.29	4.07	0.77	1.11	3.48
2023	69	30	76	68.25	1.5	1.39	1.96	0.57	0.29	0.93	3.84
TOTAL	446										
ESOX LUCIUS											
2019	55	25	54	52.5	0.55	0.77	3.11	2.34	0.75	1.4	3.18
2020	59	25	54	52.5	0.55	0.77	3.25	2.48	0.76	1.4	3.18
2021	59	25	54	52.5	1.1	1.22	1.38	0.16	0.12	1.11	3.48
2022	47	25	52	42	0.75	1.01	1.43	0.42	0.29	1.35	3.12
2023	41	32	59	57.75	1.4	1.39	0.85	-0.54	-0.63	0.99	3.67
TOTAL	261										

Cyprinus carpio

The analysis of the growth parameters and mortality rates of the species *Cyprinus carpio* during the period 2019-2023 highlights significant and relevant variations for the fish population status. The variation in the species' growth rate is influenced by external factors such as environmental conditions and exploitation through fishing. During the analyzed period, fluctuations in the growth rate are observed.

From Figures 8, 9, and 10, it can be observed that in the years 2019, 2020, and 2022, the growth rate was faster, while in 2021 it was slower.

In general, the high values of natural mortality (M) in these years indicate underexploitation of the species. This conclusion is also supported by the low values of the exploitation coefficient (E), indicating a reduced proportion of the fish population being captured by fishing. The low values of fishing mortality (F) in years with high growth rates (2019, 2020, and 2022) suggest low fishing pressure on the population. These aspects can be advantageous for maintaining fish stocks at healthy levels.

The exploitation coefficient (E) indicates the proportion of the fish population that is caught by fishing. The low values of E in these years (especially in 2019 and 2020) support the hypothesis of species underexploitation.

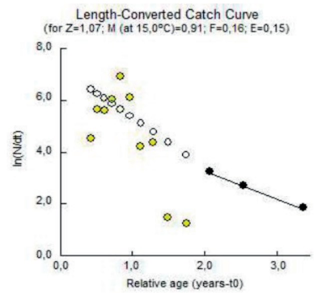

Figure 8. Growth parameters and mortality rates for *C. carpio* - 2019 (Source: original)

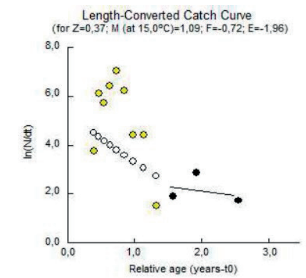

Figure 9. Growth parameters and mortality rates for *C. carpio* - 2020 (Source: original)

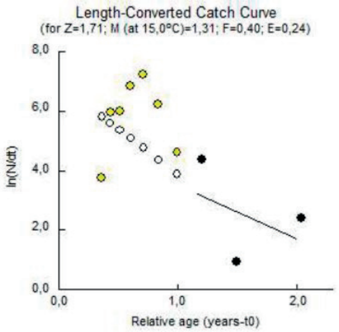

Figure 10. Growth parameters and mortality rates for *C. carpio* - 2022 (Source: original)

Regarding the years 2021 and 2023, where the exploitation coefficient E takes values of 0.57-0.55, indicating slight overexploitation. Similar results are also reported in the literature by Gheorghe et al (2011), for the carp species caught at Braila, Km 170-196.

The analysis indicates a complex relationship between growth rates, natural mortality, and fishing pressure. Understanding these interactions is essential for the sustainable management of fish resources. The changes observed in growth and mortality parameters can have consequences for population dynamics and may require adjustments in fishing management and conservation policies.

Silurus glanis

The data analysis for the species *Silurus glanis* in the period 2019-2023 reveals important information about the population dynamics and the exploitation status of the species. The growth rate (K) varies slightly from year to year, generally ranging around the values of 0.56 or 0.62.

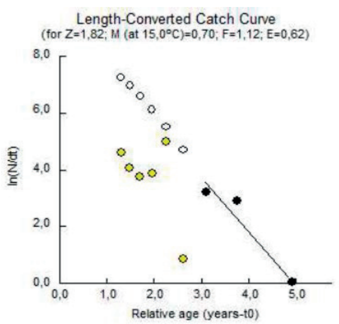

Figure 11. Growth parameters and mortality rates for *S. glanis* - 2020 (Source: original)

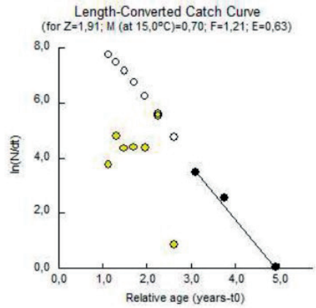

Figure 12. Growth parameters and mortality rates for *S. glanis* - 2022 (Source: original)

Natural mortality (M) remains relatively constant, with relatively high values, close to 0.66 or 0.7. The total mortality rate (Z) registers values ranging from 0.64 to 1.91, being influenced by both components, natural mortality, and fishing mortality. The slightly elevated exploitation rate in 2020 and 2022 (Figures 11 and 12) indicates a tendency of overexploitation of the species, a situation that is rectified in 2023, indicating the need for monitoring and evaluation in the future to ensure sustainable management of fish resources.

The growth parameters and mortality rates indicate a relatively stable population of the catfish during the analyzed period. The positive values of the exploitation coefficient suggest that the species is subject to moderate fishing pressure, but not at an alarming level.

Sander lucioperca

For the perch species, growth parameters and mortality rates show significant variation between the analyzed years ($p < 0.05$), reflecting possible changes due to environmental pressure and fishing activities.

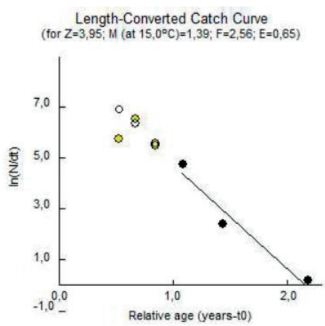

Figure 13. Growth parameters and mortality rates for *S. lucioperca* - 2020 (Source: original)

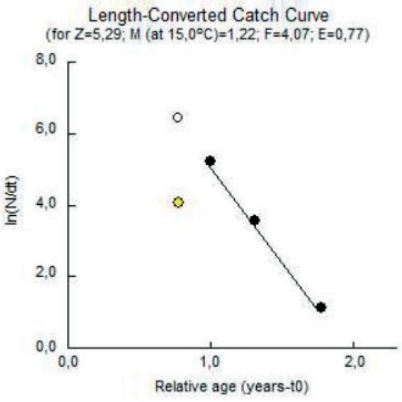

Figure 14. Growth parameters and mortality rates for *S. lucioperca* - 2022 (Source: original)

The growth rate (K) exhibits significant variations between years ($p<0.05$), ranging from 0.89 to 1.5. Natural mortality (M) remains relatively constant in the analyzed years, with values between 1.01 and 1.48.

The total mortality rate (Z) is highly variable, suggesting a significant influence from external factors on population mortality. The variable values of the exploitation coefficient indicate the need for continuous monitoring and sustainable management of fish resources for the *Sander lucioperca* species.

The analysis indicates that in the years 2020 and 2022, the growth parameter values and mortality rates for the perch species are higher compared to other years (Figures 13 and 14). Therefore, these years could be considered significant for the perch species. Specifically, in 2020 and 2022, the growth rate (K) and total mortality rate (Z) are generally higher, and the exploitation coefficient (E) indicates greater fishing pressure on the perch population.

Thus, these years can be considered significant in terms of the dynamics of the perch population and the pressure exerted by fishing activities on it. Results indicating overexploitation of the *Sander lucioperca* species in the Danube River have also been reported by Ibănescu et al., (2019) for the river section near the locality of Brăila, km 170-197.

Esox lucius

The significant variations in growth parameters and mortality rates suggest a fluctuating dynamic of the *Esox lucius* population during the analyzed period. The growth rate (K) varies significantly between the analyzed years, with values ranging from 0.55 to 1.4. Natural mortality (M) is also variable, with values between 0.77 and 1.39. The total mortality rate (Z) is variable, with values between 0.85 and 3.25. Fishing mortality (F) is also variable, with values between -0.54 and 2.48.

The exploitation coefficient (E) is variable and indicates the fishing pressure on the population. The values are generally positive, except for the year 2023, indicating moderate to high fishing pressure on the species.

The years 2019 and 2020 recorded higher values of mortality rates and exploitation coefficients, indicating greater pressure on the population due to fishing activities (Figures 15 and 16).

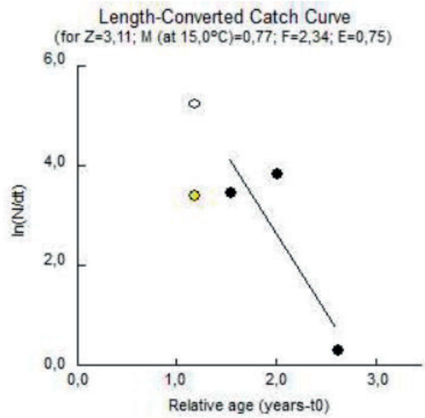

Figure 15. Growth parameters and mortality rates for *E. Lucius* - 2019 (Source: original)

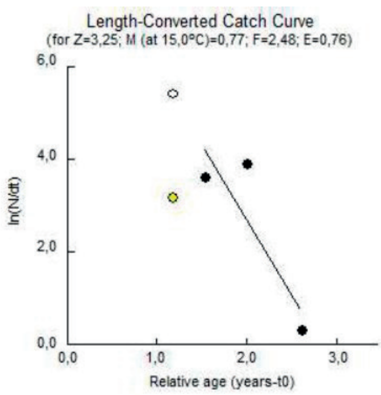

Figure 16. Growth parameters and mortality rates for *E. lucius* - 2020 (Source: original)

The year 2023 stands out with negative values of fishing mortality and exploitation coefficient, which may indicate underexploitation of the species in this year. (Figure 17)

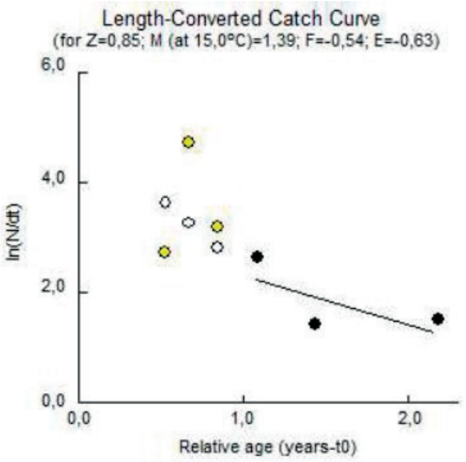

Figure 17. Growth parameters and mortality rates for *E. lucius* - 2023 (Source: original)

The data analysis for *Esox lucius* shows significant variation in growth parameters and mortality rates in the studied period (2019, 2020, 2023) can be considered important years due to significant changes observed in these parameters.

CONCLUSIONS

The studied species are important, both economically and ecologically, which is why the estimated population parameters serve as a benchmark in the development of stock assessment.

The impact of climate changes on the environment, especially on the water temperature and level of the Danube River has been evident in recent years. Rising temperature and water level variability have a significant influence on the aquatic ecosystem and fish species behaviour.

Changes in water temperature and level determined fluctuations in fish habitat and distribution, affecting biological cycles, migration and availability of reproduction and feeding areas.

Comparative analysis of reported catches and allowable fishing limits has revealed a trend of overexploitation of commercially valued fish species in the lower Danube sector. Although there are regulations and fishing quotas established to maintain sustainable exploitation of resources, reported catches have consistently exceeded allowable limits in the analyzed period.

Economically valued fish species such as carp, catfish, pikeperch, and pike have shown significant variations in growth parameters and mortality rates during the analyzed period. These variations can be attributed to multiple influences, including changes in environmental conditions, fishing pressure, and alterations in aquatic habitats.

The study has highlighted the need for more efficient and sustainable management of Danube fish resources, considering the impact of climate change and fishing pressures. Recommendations for the future include continuous monitoring of fish stocks, adjusting fishing quotas based on population dynamics, and implementing sustainable fishing practices.

In conclusion, climate change poses a significant threat to fish populations in the Danube, and proper management of these resources becomes increasingly urgent in the context of environmental fluctuations and anthropogenic pressures. Continuous monitoring and conservation actions are ways to ensure the sustainability of fishing and aquatic ecosystems in the future of the Danube.

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