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SEX STRUCTURE AND FECUNDITY OF PONTIC SHAD (*Alosa immaculata*) IN THE ROMANIAN SECTOR OF THE DANUBE RIVER

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Abstract

*The Pontic shad (Alosa immaculata), a migratory fish species of significant ecological and economic importance, is a key component of the ichthyofauna in the Danube River and Black Sea. This study investigates the sex structure and fecundity of Alosa immaculata during its breeding migration, focusing on specimens from the Romanian sector of the Danube River. Sampling was conducted from March to May every year from 2020 to 2024, coinciding with the peak reproductive season. Biological parameters like total length, body weight, and gonad weight will be recorded, while age determination will rely on scale analysis. Absolute individual fecundity (F) will be determined using the weighing method. Relative fecundity (RF) will be calculated by: RF = F*GW/ws, where GW = the gonadal weight of fish and ws = the weight of the sample. The study seeks to fill critical gaps in understanding the reproductive biology of A. immaculata, essential for developing conservation strategies and sustainable fisheries management. The findings will provide insights into population dynamics, aiding in the preservation of this species amid increasing anthropogenic pressures and environmental changes.*

Key words*: conservation, fisheries management, prolificity, reproductive biology, sex ratio.*

INTRODUCTION

The Pontic shad (*Alosa immaculata* Bennet, 1835), a migratory fish species of the Clupeidae family, plays a crucial ecological role as a key component of the ichthyofauna and holds significant economic importance for the Danube–Black Sea region (Ţiganov et al., 2016; Leonov et al., 2022; 2023). Its anadromous life cycle, characterized by migrations from marine to freshwater environments for reproduction, is essential for maintaining population stability and ecological balance. This migration ensures the species' survival by providing optimal conditions for larval development and contributes to biodiversity by transferring nutrients between marine and freshwater ecosystems. Additionally, it facilitates genetic diversity, preventing inbreeding and strengthening the population's resilience to stress factors (Tamario et al., 2019).

Historically, *A. immaculata* undertook extensive upstream migrations, reaching spawning areas up to 1,000 km from the river's mouth. However, anthropogenic pressures such as overfishing, water pollution (Năvodaru & Waldman, 2003; Višnjić-Jeftić et al., 2010), reduced water levels (Năvodaru & Waldman, 2003; Smederevac-Lalić et al., 2018), and the construction of the Iron Gates I and II dams have significantly disrupted these migratory routes. As a result, the species is now largely restricted to the lower Danube River, limiting access to its traditional spawning grounds (Năvodaru, 1996; Mocanu et al., 2020). These disruptions have negatively impacted its reproductive success, a critical factor for

population sustainability (Višnjić-Jeftić et al., 2013).
According to official data from the Romanian National Agency for Fisheries and Aquaculture, Pontic shad catches have declined from 634.5 tons in 2019 to 271.25 tons in 2023 (*NAFA, 2022*). A similar decline in catches was reported by Raikova-Petrova et al. (2013) and Višnjić-Jeftić et al. (2013) in the Bulgarian sector of the Danube River. The same goes for the Pontic shad captures from the Dniester River, in the Moldavian Republic (Gologan, 2021), suggesting a possible trend of *A. immaculata* population decline, at large scale. These findings highlight the urgent need for an integrated conservation approach among riparian countries to prevent further population decline and ensure the long-term viability of this ecologically and economically important species.
Fecundity is a fundamental concept in reproductive biology, referring to an organism's potential reproductive capacity, typically measured by the number of eggs produced per reproductive cycle (Lambert, 2008). It is influenced by both intrinsic and extrinsic factors, including species - specific reproductive strategies, body size, age, nutritional status, and environmental conditions such as water temperature, food availability, and habitat quality (Murua et al., 2003; Raikova-Petrova et al., 2013).
The lifespan of *A. immaculata* is estimated at 7-8 years, with sexual maturation occurring at 3-4 years of age. Only a small fraction of individuals spawn in two consecutive seasons (Năvodaru & Năstase, 2014; Țiganov et al., 2016). In most studies, fecundity is expressed as potential annual fecundity.
Despite the ecological and economic significance of *A. immaculata* in the Romanian sector of the Danube River, there is a lack of detailed research on its reproductive biology, particularly regarding sex structure and fecundity. These knowledge gaps hinder the development of effective conservation strategies and sustainable management practices, especially in the face of increasing anthropogenic and environmental pressures.
This study investigates the sex structure and fecundity of *A. immaculata* during its breeding migration in the Romanian sector of the Danube River. Spawning occurs between late February and early March when water temperatures reach approximately 5-6°C (Năvodaru, 1997), coinciding with the seasonal rise in Danube water levels (Ciolac, 1998; 2004).

MATERIALS AND METHODS

The Pontic shad (*Alosa immaculata*) specimens were collected during scientific fishing surveys conducted by the I.C.D.E.A.P.A. Galați researchers in the Chiscani area, Braila County (Figure 1), located in Sector 2 of the Danube River, between Braila (km 169) and Gropeni (km 197). This area represents a critical habitat for the species, serving as an essential spawning ground, as well as a key migratory corridor.

Figure 1. Chiscani Area – Study zone (Source: https://browser.dataspace.copernicus.eu/)

Data Collection. Sampling was carried out annually from March to May, spanning the years 2020 to 2024, coinciding with the peak reproductive season. A total of 1,554 individuals were captured using gillnets with a mesh size of 30-35 mm. The specimens were selected through a random sampling method from commercial catches, ensuring the inclusion of individuals from all length classes.
Total length (TL, cm) was measured with an ichthyometer, with an accuracy of 0.1 cm. The total weight (TW, g) and gutted weight (w, g) were determined using an electronic weighing scale with a precision of 0.01 g. Gonads were weighed with an accuracy of 0.0001 g. Length classes were established at 2 cm intervals.

Age determination was made with the use of scales collected from the anteromedial part of the body, above the lateral line. Therefore, using a stereomicroscope with a magnification of 1 x 10, the rings obtained on the scales were counted indicating the annual growth (Yilmaz and Polat, 2002).

Statistical Analysis. Statistical analyses were performed using XLStat Basic 2024.4.0 and R 4.2.2 software, following Pearson (1900) and Berk & Jones (1979).

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). The Chi-square test was employed to assess deviations from the expected 1:1 ratio (Raikova-Petrova et al., 2013; Rashid, 2018). The test compares observed and expected frequencies using the formula:

$$\chi^2=\sum\frac{(Oi-Ei)^2}{Ei},$$

where *Oi* represents the observed frequency and is *Ei* the expected frequency (calculated as 50% of the total population). The calculated values were compared with critical values at a confidence level of 0.05 and df = 1. If the calculated χ^2 value exceeded the critical value, the null hypothesis was rejected, indicating a significantly different sex distribution in the population. The obtained results were then interpreted to assess the balance or imbalance of the sex distribution within the studied population.

Absolute and relative fecundity. Individual fecundity, the number of eggs for one gram of sample was determined by the gravimetric method.

The absolute fecundity (F) was calculated using the formula: F = No. of eggs* GW/ws, where GW is the gonadal weight and ws is the sample weight (Alam & Pathak, 2010; Das et al., 2016; Roy et al., 2014), in our case 1 g/sample, while relative fecundity was determined by RF = F/TW (kg).

The normality of relative fecundity data was tested using the Shapiro-Wilk test. If $p<0.05$, the null hypothesis (H_0) of normal distribution was rejected, indicating non-normal data. Due to non-normal distribution, for both absolute and relative fecundity, which displayed a flat distribution with extreme values and negative skewness, suggesting that most values are concentrated in the upper part of the distribution, but there are also a few significantly smaller values that influence the mean, the Kruskal-Wallis test was applied to determine significant differences between years (Maruska & Fernald, 2010).

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 the distribution of fecundity values across different annual groups (Siegel & Castellan, 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).

The gonadosomatic index (GSI) was calculated to assess reproductive condition using the formula: GSI (%) = GW/TW*100 (Hasan et al., 2020). Normality was verified via the Shapiro-Wilk test ($p>0.05$ for all years) and variance homogeneity was confirmed using Bartlett's test ($p>0.05$, $\chi^2 = 7.52 < \chi^2_{critical} = 9.49$). Further analysis included ANOVA Single Factor (df1 = 4, df2 = 81, α = 0.05), where a significant result ($\hat{F}$ = 3.94>$F_{critical}$ = 2.48) indicated heterogeneity among years. Tukey's test was then used to identify specific differences (α = 0.01).

Additionally, the relationship between absolute fecundity and morphometric parameters were established to determine how reproductive output varies with body size, providing insights into the factors influencing fecundity and the overall reproductive potential of *Alosa immaculata*. These relationships help assess the impact of biological and environmental factors on egg production, contributing to a better understanding of population dynamics and the development of effective conservation and management strategies.

RESULTS AND DISCUSSIONS

Out of a total of 1554 specimens, 838 were females and 716 were males, suggesting a significantly imbalanced sex distribution within the studied population, with a higher number of females compared to males (53.93% females and 46.07% males). The most numerous females belong to the length class of 29-30.9 cm and are 4 years old – 168 specimens.

The same length and age class also contains the highest number of males – 170 specimens (Table 1).

Relatively small length classes were found by Rozdina et al. (2025) in the Black Sea, up to 20.9 cm. The age distribution revealed that most individuals are found in the 3-5 age groups, unlike previous years when the migration age for reproduction ranged from 2-7 years (Năvodaru & Waldman, 2003). Similar results were observed by Năstase et al. (2019) for the year 2016, with most of the spawner specimens in the Danube Delta falling into the 2-5 age classes, and by Crepis et al. (2018) in the Dniester River, where most specimens were between 4-5 years old.

In contrast, Raikova-Petrova et al. (2013) observed a predominantly younger population in 2010-2011 in the Bulgarian section of the river, with individuals in the 2-3 age classes. Sporadically, 8-year-old specimens were found (3 females and 1 male).

Table 1. Total distribution of Pontic shad individuals by sex, length classes, and age

Size classes (cm)	Age (t, years)														TOTAL
	2		3		4		5		6		7		8		
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	
15-16.9	2	0	0	2	0	0	0	0	0	0	0	0	0	0	4
17-18.9	0	2	7	5	0	0	0	0	0	0	0	0	0	0	14
19-20.9	1	2	0	2	2	0	0	0	0	0	0	0	0	0	7
21-22.9	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7
23-24.9	1	2	1	1	1	1	0	0	0	0	0	0	0	0	7
25-26.9	0	4	5	8	1	17	0	7	1	0	0	0	0	0	43
27-28.9	2	0	5	72	37	98	19	63	0	4	0	2	0	0	302
29-30.9	4	7	36	54	168	170	73	74	21	11	2	0	0	1	621
31-32.9	0	3	22	9	133	41	107	28	20	6	0	0	3	0	372
33-34.9	0	0	7	3	51	8	65	2	13	0	2	0	0	0	151
35-36.9	0	0	0	0	14	0	4	0	5	0	0	0	0	0	23
37-38.9	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2
39-40.9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
TOTAL	10	20	83	163	408	335	269	174	61	21	4	2	3	1	1554

These data suggest that the population is concentrated in the younger age groups, indicating an active and rapid development phase. In the 2-3 age classes, males dominate, while in the 4-8 age classes, females are the majority.

Sex Ratio Analysis

Through the application of the χ^2 test, we obtained a χ^2 value of 9.58, which is significantly higher than the critical value of 3.841 (for a 0.05 significance level and 1 degree of freedom). Therefore, the null hypothesis is rejected, indicating that the sex distribution is not balanced, suggesting a predominance of one gender in the analyzed sample, in this case, females.

These observations suggest an active and young population, with a significant concentration in medium and long-length intervals, accompanied by a predominance of females. The ratio of females to males in the studied population shows a slight predominance of females, with a ratio of approximately 1.17 females for each male (53.93% females and 46.07% males).

A relatively low ratio (M/F = 0.51) compared to the results of this study was observed in 2016 at the Danube Delta mouth into the Black Sea by Năstase et al. (2019), indicating the presence of 2 females for each male. Similar results were also reported by Rozdina et al. (2025) in the Bulgarian section of the Danube, with a M/F ratio of 1:2.6. High values were also obtained by Crepis et al. (2018), with an M/F ratio of 1:6 for the Dniester River. In contrast, Raikova-Petrova et al. (2013) observed a clear dominance of males in 2010-2011, with a ratio of 5.61:1, highlighting a significant shift in the structure of the population in the last decade. Furthermore, a higher female ratio may contribute to an increase in the overall fecundity of the population.

The sex structure remains consistent across different length and age classes, without significant variations between age groups, suggesting that the sex imbalance is not caused

by age or length-specific selection factors. The sex ratio depends on the catch period, as the migration seems dominated by males at the beginning of migration, coming to balance during the peak and dominated by females at the end of the process (Lambert et al., 2001).
Analyzing the M/F ratio over the years (Figure 2), it is observed that in most cases, females outnumber males, with ratios ranging from near equality (2023) to a greater imbalance in favor of females (2022 and 2024).

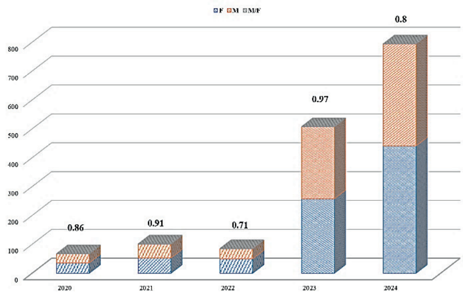

Figure 2. Sex Ratio Trend for Pontic shad between 2020 and 2024 (Source: original)

This suggests that various factors could be influencing the observed sex ratio. Another possible hypothesis could be related to external factors influencing the sex distribution. For example, environmental conditions in the studied regions (such as water temperature or resource availability) might favor a certain sex ratio depending on developmental or survival factors. These effects could vary between the studied years or based on the locations from which the individuals originate. Moreover, the influence of external pressures such as fishing practices or ecological disturbances could alter the balance between the sexes. These factors might vary over time, contributing to the fluctuations observed in the M/F ratio.

Absolute and relative fecundity

For the fecundity analysis conducted between 2020 and 2024, 86 samples aged between 2 and 4 years, with varying weights and lengths, were included. Individual fecundity varied significantly, with a minimum of 4,985 eggs/g recorded in 2022 for a 3-year-old specimen weighing 196 g and measuring 27.9 cm in total length (TL), while the maximum value of 19,213 eggs/g was observed in 2021 for a 5-year-old individual weighing 305 g and measuring 30.4 cm in TL. The average individual fecundity during the study period was 9,260.79 eggs/g ± 331.74 eggs/g, in contrast to the average obtained by Năvodaru & Waldman (2003), which was 3,122 eggs/g.
As shown in Table 2, the average values for the absolute fecundity situated ranged from 103880.9 eggs/g ± 25068.7 eggs/g in 2024 and 160441.8 eggs/g ± 56592.5 eggs/g in 2020, while the relative fecundity was situated between 376190 ± 104095.5 in 2023 and 593197.5 ± 71777 in 2022.

Table 2. Statistical parameters for absolute and relative fecundity between 2020 and 2024

	Absolute fecundity				
	2020	**2021**	**2022**	**2023**	**2024**
Mean	160441.8±56592.5	142904.3±40747.1	100902.6±15158.3	117288.6±49549	103880.9±25068.7
Minimum	56584.80	84869.95	75731.32	29539.13	70292.04
Maximum	283131.80	245004.75	128729.30	183136.40	161220.76
	Relative fecundity				
	2020	**2021**	**2022**	**2023**	**2024**
Mean	521176.2±62609.2	593197.5±71777	407121.9±29986	376190±104095.5	402331.1±28218.4
Minimum	420540.65	451435.90	369081.21	167812.89	351885.17
Maximum	625920.00	761200.82	453587.02	492129.77	448043.22
	Annual water temperature				
Mean	14.71	14.12	14.93	14.92	15.57

For both absolute fecundity ($p<0.05$ and $\chi^2 = 19.742 > \chi^2\_critical = 9.49$, with df = 4 and $\alpha = 0.05$) and relative fecundity ($p<0.05$ and $\chi^2 = 57.857 > \chi^2\_critical = 9.49$, with df = 4 and $\alpha = 0.05$), the Kruskal-Wallis tests indicated significant difference between years, meaning that at least one year has a significantly different distribution compared to the others (Figure 3 a, b).

a)

b)

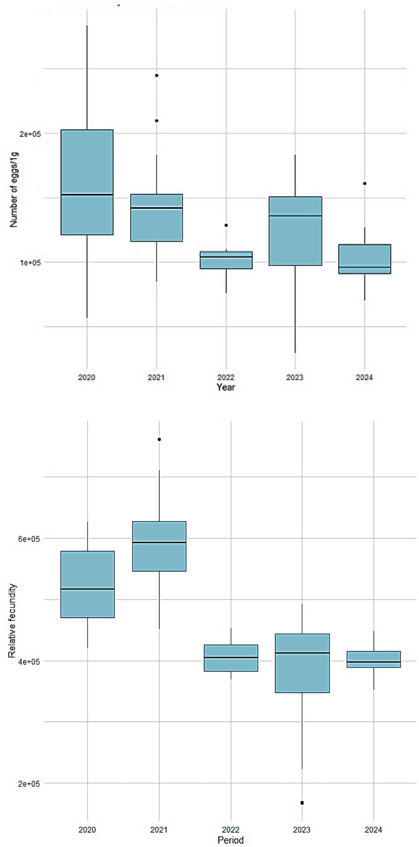

Figure 3 Variations between years in fecundity a) F; b) RF (Source: original)

The results show low values of absolute fecundity compared to those obtained by Raikova-Petrova et al. (2013), where the average fecundity reached up to 41,814 eggs in the 2010-2011 period.

The Dunn test, adjusted with the Bonferroni correction, showed significant differences between the absolute fecundity within the following years: 2020 vs. 2022 and 2020 vs. 2024 ($p<0.05$), suggesting that absolute fecundity was not constant across the years, indicating that ecological or biological changes may have influenced these values.

In case of RF, the variations were displayed differences between all years, but the most significant was 2021, when the relative fecundity was lower than the rest of the years. There are two possible explanations that emerge. First, the egg production was lower than the rest of the years, which means that fish directed their energy more to growths and less to reproduction. Second, the individuals had a better body condition in 2021, thus reducing the RF value.

Regarding the GSI analysis, statistical tests revealed very significant differences (FS), especially between the years 2022-2023 and 2022-2024 ($\alpha = 0.99$) (Figure 4). These significant differences could indicate ecological, climatic, or biological changes that occurred during that period. The gonadosomatic index is a method used to measure the sexual maturity of the species in relation to the development of ovaries.

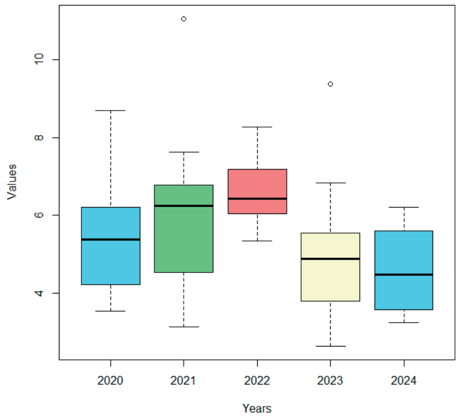

Figure 4. GSI Distribution per year for Pontic shad 2020-2024 (Source: original)

The trend in the average GSI values during this period was dome-shaped, with a maximum GSI of 6.65 reached in 2022 and a minimum GSI of 4.67 in 2024, which confirmed that relative fecundity decreased as the years progressed. The maximum GSI value in 2022 indicated that the species encountered favorable reproductive conditions that year. The minimum value per individual was 2.62, while the maximum was 11.06, values higher than those in 1987, which ranged from 2.61 to 9.14 (Năvodaru & Waldman, 2003).

Similar values were observed for the species *Alosa fallax* between 2022 and 2023 by Więcaszek et al. (2024) in the Szczecin Lagoon, Poland, another important spawning ground for the *Alosa* genus, like Chiscani, with values ranging from approximately 128,000 to 158,000. As an anadromous species, *Alosa fallax* (Lacépède, 1800) exhibits a migratory behavior similar to that of the Pontic shad, traveling from marine environments to rivers or freshwater for spawning.

Correlating the RF with GSI (Pearson = 0.34), TW (Pearson = 0.10) and mean water temperature (Pearson = -0.81), resulted the existence of a strong negative influence of water temperatures that underlines the negative effect of temperatures variations on relative fecundity. As stated by Bowden (2008) and Rohlenová et al. (2011), the elevated temperatures can weaken the fish immune system, consuming energy reserves for survival, while other physiological tasks (e.g. growth, reproduction) are neglected.

Absolute Fecundity in relation to biological parameters

The 2020 exhibits an ascending trend in absolute fecundity in relation to total length (TL), age (t, years), and weight (TW) (Figure 5 a, b, c).

This trend is confirmed by the Pearson correlation coefficient, which reached significant positive values: 0.93 for Lt, 0.96 for age, and 0.95 for weight. These results suggest that as body parameters increase, the reproductive capacity of the individual intensifies. The coefficient of determination (R^2) of 0.8726 indicates that 87% of the variation in F can be explained by the variation in total length (TL). Additionally, for weight and age, the R^2 coefficients were 0.9074 and 0.9183, respectively, suggesting a significant influence of these parameters on absolute fecundity.

The determination relationships between F and body parameters are as follows:

- F = 15,871 * Lt – 33,1256;
- F = 624.69 * TW – 29,231;
- F = 50,800 * t – 27,707.

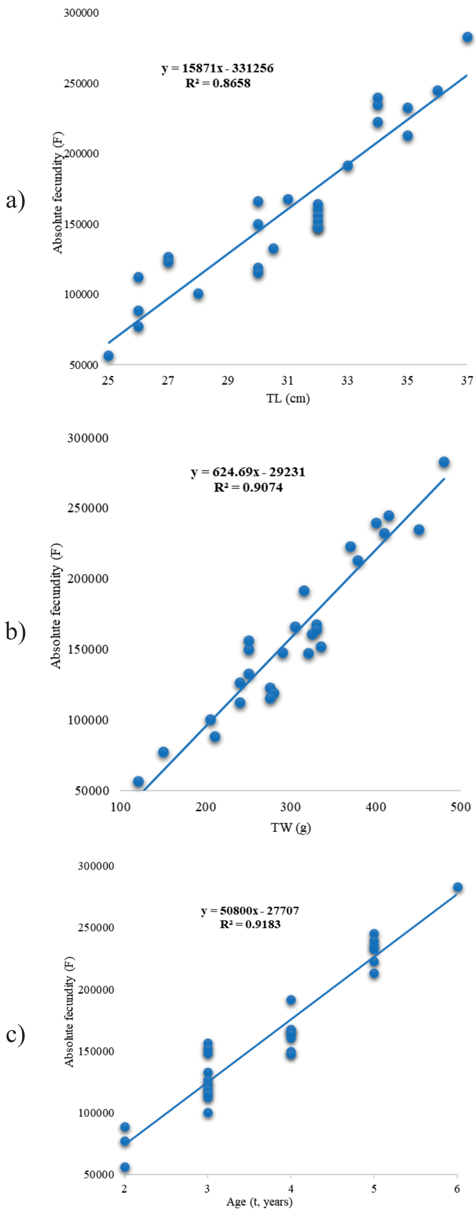

Figure 5. Absolute fecundity in relation to biological parameters for Pontic shad in 2020: a) F vs. TL; b) F vs. TW; c) F vs. Age (Source: original)

In 2021, the correlations between F and body parameters remain high, similar to the previous year (Figure 6).

The Pearson correlation coefficient reached 0.93 for weight (TW), 0.84 for total length (TL), and 0.96 for age (t).

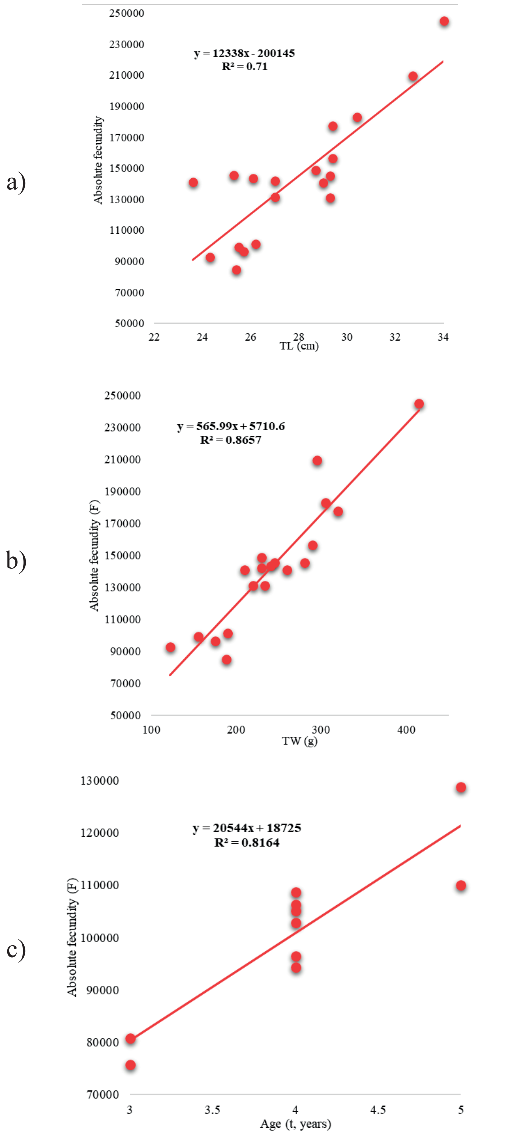

Figure 6. Absolute fecundity in relation to biological parameters for Pontic shad in 2021 a) F vs. TL; b) F vs. TW; c) F vs. Age (Source: original)

As shown in Figure 6 (a, b, c) and by the high values of the R^2 coefficient, age and weight are the best predictors of absolute fecundity, with R^2 values of 0.91 and 0.87, respectively. Although total length significantly influences fecundity, it has a weaker correlation compared to weight and age.

The models established for this year are:

F = 565.99 * TW – 5710.6;

F = 12338 * TL – 200145;

F = 39027 * t – 13203.

In 2022, the influence of body parameters on F remains significant. The Pearson coefficient is high for total length (0.86), age (0.90), and weight (0.91). Analyzing the variability of F, it is observed that 83.29% of its variation can be explained by weight variation, 74.83% depends on total length, and 81.64% on age (Figure 7 a, b, c).

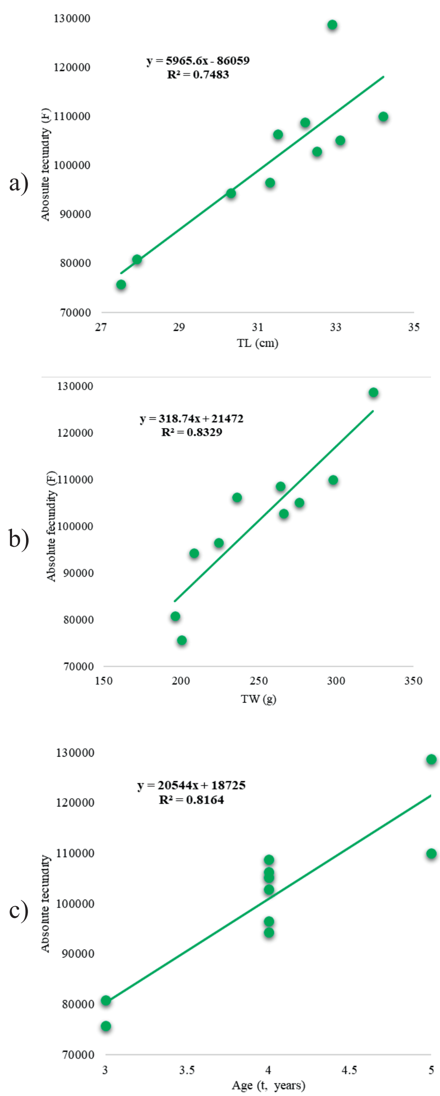

Figure 7. Absolute fecundity in relation to biological parameters for Pontic shad in 2022: a) F vs. TL; b) F vs. TW; c) F vs. Age (Source: original)

Additionally, the positive intercept suggests a minimum fecundity of approximately 21.472 units at lower weights.

The determination relationships are:
F = 318.74 * TW + 21472;
F = 5965.6 * TL – 86059;
F = 20544 * t + 18725.
In 2022 as well, weight (TW) and age (t) are the strongest predictors of absolute fecundity, suggesting that absolute fecundity increases with the size and age of the fish, which is characteristic of many oviparous fish species.
In 2023, the correlations between F and body parameters remain significant, with notable correlations for age, total length, and body weight (Figure 8 a, b, c). The determination relationships are:
F = 524.95 * TW – 39496;
F = 7232.2 * TL – 86927;
F = 40221 * t – 64763.

Additionally, all three relationships suggest that F increases as age, length, and body weight increase. Total length (TL) is strongly correlated with F (R^2 = 0.8742) and is considered the best predictor. Among these factors, total length (TL) has the strongest correlation with RF (R^2 = 0.8742), suggesting that body size is a better predictor for fecundity than age or weight.
The trend observed in 2023 continues in 2024, with strong relationships between F and body parameters (Figure 9 a, b, c). The coefficient of determination R^2 suggests that weight (TW) has the strongest correlation with F (R^2 = 0.918).
The relationships are:
F = 377.67 * TW + 5950.7;
F = 7187.8 * TL – 99730;
F = 23190 * t + 23769.

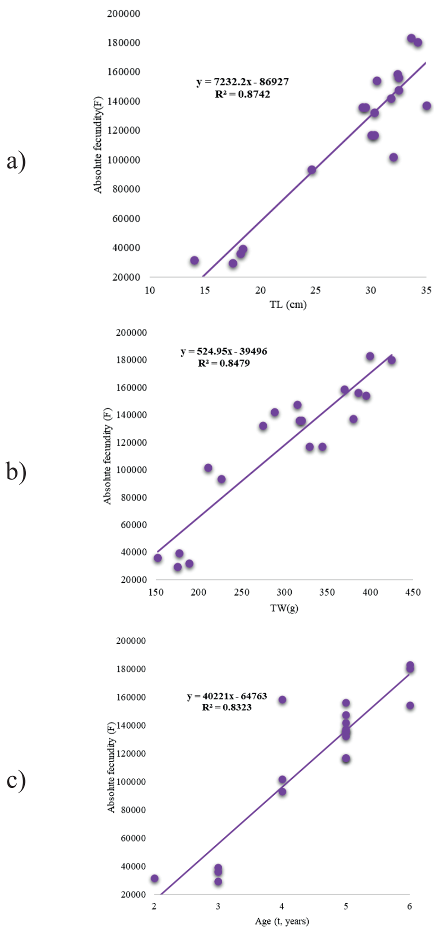

Figure 8. Absolute fecundity in relation to biological parameters for Pontic shad in 2023: a) F vs. TL; b) F vs. TW; c) F vs. Age (Source: original)

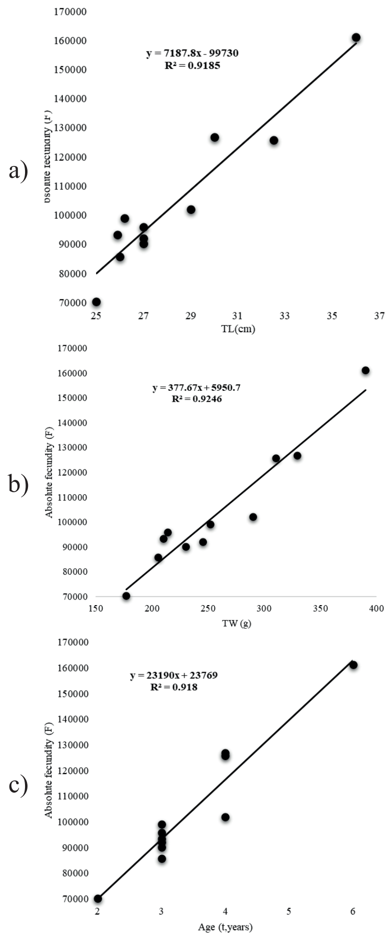

Figure 9. Absolute fecundity in relation to biological parameters for Pontic shad in 2024: a) F vs. TL; b) F vs. TW; c) F vs. Age (Source: original)

As Murua et al. (2003) stated, the study showed the relationship between the reproductive capacity of the shad specimens and body size, allowing for the estimation of how many eggs are produced by a specific stock of reproductive shad, considering factors such as size, age, and length of the fish. This was also confirmed by Raikova-Petrova et al. (2013) and Năvodaru & Waldman (2003). This is important for fishery resource management, as it enables the assessment of a population's ability to sustain and regenerate itself.

On the other hand, the results from Rozdina's (2015) study on the shad in the Bulgarian Danube area suggested an inverse relationship between absolute individual fecundity and the fish's weight, meaning that fecundity decreases as the linear growth rate and weight of the fish increase.

CONCLUSIONS

The study highlighted a significant correlation between biological parameters, such as weight, length, and age, and the relative fecundity of the Danube shad. These correlations suggest that body size and age are important predictors of reproductive capacity, confirming trends observed for many oviparous fish species. Thus, evaluating these parameters can provide valuable information for managing and conserving fishery resources.

The predominance of females in shad populations could indicate a stressed population, but it may also be the result of fluctuating cohort strength and different ages at maturation between males and females. An imbalanced sex ratio can influence reproductive processes and may suggest higher selective pressure on males. This imbalance could affect the long-term structure of the population, with potential implications for its stability.

Data collected for the years 2020-2024 suggest a downward trend in absolute fecundity, which may reflect ecological, biological, or environmental changes that have affected the reproductive capacity of Danube shad. It is essential to monitor these changes to identify the causes behind this decrease and to take appropriate actions.

In light of the decrease in absolute fecundity observed in recent decades, it is recommended to study the causes behind this decline. Comparing current data with historical records will help identify the extent to which temperature fluctuations contribute to this trend. Understanding the biological, ecological, and environmental drivers behind these changes is crucial for developing effective conservation and sustainable management strategies for shad populations.

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