RESEARCH ARTICLE

First Evidence of Infestation with *Anguillicola Crassus* in European Silver Eel (*Anguilla Anguilla*) in the Shkodra/Skadar Lake, Albania

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Abstract

The European eel (*Anguilla anguilla*) plays a significant role in the biodiversity and fishing activities throughout Europe and the Mediterranean Sea. However, their populations have declined drastically, now constituting less than 10% of their historical numbers. This decline is attributed to various factors, both human-induced and ecological, including an invasive parasitic disease caused by the nematode *Anguillicola crassus*. Research on this parasite in the freshwater systems of Albania is limited. This study, the first of its kind, investigates the level of infection caused by *A. crassus* in Lake Shkodra/Skadar, the largest lake on the Balkan Peninsula. In December 2024, a total of 141 silver eels were collected for sampling. Biometric data were recorded, and sagittal otoliths were removed for age determination. Infestation was assessed macroscopically by inspecting the swim bladder, and classical epidemiological parameters—prevalence, mean intensity, and mean abundance—were evaluated. The prevalence of *A. crassus* in Shkodra/Skadar Lake was found to be 36.9%, with higher infection rates observed in males and younger eels. The number of adult *A. crassus* parasites found per infected eel ranged from 1 to 5, with males exhibiting a significantly higher infection rate of 48.4%, compared to 27.8% in females. The positive cases were found in silver eels aged 4 to 10 years, with the highest prevalence noted in the 4-year-olds (30.96%). Further investigative work over several years is necessary to provide a more comprehensive understanding of the infection of migratory silver eels with *A. crassus* in Lake Shkodra.

Keywords: European eel**,** *Anguillicola crassus*, swim bladder, parasite prevalence.

1. Introduction

The European eel (*Anguilla anguilla L.*) is a catadromous fish species of significant economic, cultural, and ecological importance throughout Europe and the Mediterranean Sea basin [1]. This species was once abundant, populating rivers, their estuaries, and coastal lagoons. Historically, the eel has also supported both commercial and artisanal fishing, playing a crucial role in the aquatic food chain as both predator and prey [2]. Despite its former abundance, over the past four decades, the population of European eels has experienced a drastic decline across all age categories, leading to a reduction of more than 90% in their stock compared to the 1970s [1].

The notable decrease can be linked to various factors such as overfishing [3], habitat loss, degradation, river fragmentation, wetland reduction and drying [4] ,

obstacles to migratory breeding [5], environmental pollution [6], and climate change [7;8].

Among these threats, parasitic infections, especially from the nematode *Anguillicola crassus*, significantly impact the health and survival of eels [9;10]. *A. Crassus* was introduced into European waters in 1982 [11], and from that point onward, it rapidly spread across the continent [12]. This parasite completes its adult biological form within the eel's swim bladder, damaging the organ's lateral walls and consequently impairing its functional role [13]. Laboratory studies have shown that infected eels may exhibit reduced swimming performance, increased energy expenditure, and immunodepression against secondary infections [14;15]. Also, the parasite compromises the eel's ability to migrate, thereby further diminishing the likelihood

of successful gamete release in the breeding grounds [16]. Understanding its biological cycle and epidemiology would be crucial in formulating the most effective management and conservation strategies for the European eel species [17].

To date, no study has been conducted to assess the prevalence of *A. crassus* infestation in the European eel

2. Material and Methods

2.1. Studied area

in Albania. This study examines Lake Shkodra/Skadar, which is the largest in surface area on the Balkan Peninsula and is transboundary, lying between Albania and Montenegro. The following study addresses the prevalence of *A. crassus* infestation according to age and sex, through macroscopic examination.
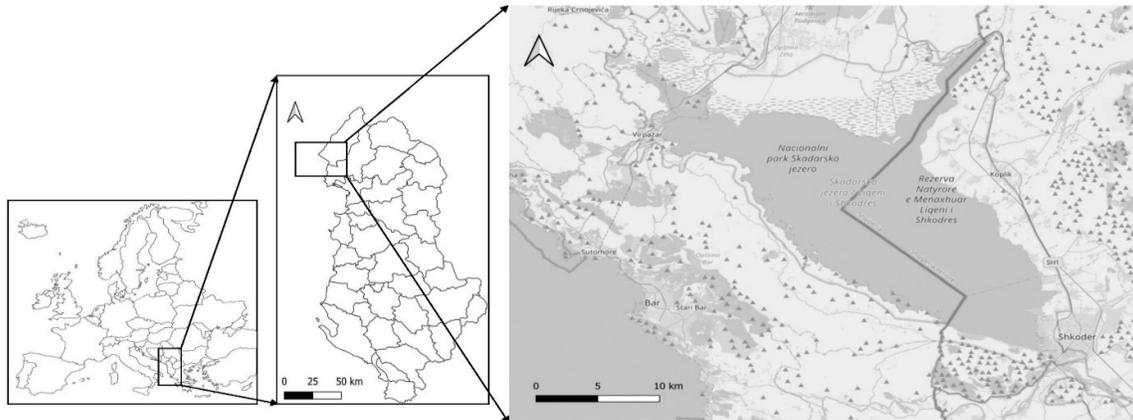

Figure 1. Location of the European eel habitat (Shkodra/Skadar lake) in the Albanian territory (map based on dataset of the GADM created with QGIS 2025; QGIS Development Team 2025)

2.2. Samples collection

A total of 141 European eels in the silver stage were collected from the Shkodra/Skadar/ at the end of December 2024. The Fisheries Management Organizations overseeing Lake Shkodra/Skadar collected the data at the fish barrier of Shkodra/Skadar Lake. The goal was to sample migrating eels, assess their health status, and exclude non-migratory individuals. The fish barrier was extended along the entire channel that connects the lake with the Buna/Bojana river; fishing gear was placed behind the barrier. It is important to note that sampling from the commercial catch does not require an animal ethics permit.

For the Biometrics and dissection procedure, the silver eel samples were analyzed using a combination of biometric data, including fish length (measured in mm), mass (measured in g), stage of sexual maturity, eye diameter, pectoral fin length, sex, visceral fat index, and swim bladder condition. They also determined the age of the eels by examining their otoliths.

The Fulton condition factor (k) for each eel specimen was calculated based on their weight and length records [18].

Visceral fat was measured by fat scores from 0-3. Four scores as described by Simon et al [19].

The method used to estimate the age of eels is based on ICES [20]. This procedure adapts the technique established by Moriarty [21], which involves a cutting and burning test for recognizing annuli.

2.3. Parasite's examination

Each fish was assessed for *Anguillicola crassus* infestation. A macroscopic examination of the swim bladder of each eel (n = 141) was performed to determine the presence of adult stages of the invasive parasite *A. crassus*. Key parameters of parasite population dynamics—prevalence, mean intensity, and mean abundance [22]—were calculated. The condition of the swim bladder was recorded, following a method similar to Hartmann [23].

2.4. Statistical analysis

All analyses were performed using R software [24].

Whether the samples and, if applicable, the residuals of the samples originate from a normally distributed population was tested at a significance level of 0.1 using the Kolmogorov–Smirnov test. The subsequent check of the values for variance homogeneity was

performed at a significance level of 0.1 using the Levené test. As a result, the non-parametric Mann–Whitney (Wilcoxon) test was selected as the most suitable statistical method to compare groups. A p-value below 0.05 was considered statistically significant.

The prevalence of infestation in silver-stage European eels (*Anguilla anguilla*) was evaluated according to age and sex. A total of 141 eels, were examined for parasite presence. Prevalence was calculated as the proportion of infested individuals relative to the total number of individuals examined within each age class. Age-specific prevalence was further stratified by sex to assess potential differences between males and females. Descriptive statistics, including percentages and frequencies, were used to summarize the data. Results were expressed as the number of positive cases over the total analyzed in each age-sex group.

3. Results

3.1. Morphometrics

Table 1. Results for the biometric parameters analyzed in this survey

Analyzed parameter		Shkodra/Skadar Lake			
		Mean	SD	Min.	Max.
length [cm]	♂	41.1[a]	3.13	35.0	47.5
	♀	59.6[b]	5.9	48.2	75.0
weight [g]	♂	105.8[a]	32.4	66.0	188.0
	♀	389.6[b]	133.8	182.0	924.0
Fulton condition index [**k**]	♂	0.167[a]	0.012	0.14	0.21
	♀	0.178[b]	0.018	0.118	0.261
age [year]	♂	6.9[a]	2.1	4	10
	♀	8.0[b]	2.4	5	14
eye diameter [mm]	♂	8.3[a]	1.3	6.6	10.8
	♀	9.6[a]	1.0	6.7	11.1
pectoral fin length [mm]	♂	24.9[a]	5.5	18.3	35.7
	♀	27.3[b]	5.2	10.2	35.8
fat index	♂	1.7[a]	0.6	1.0	2.5
	♀	2.0[b]	1.00	1.0	2.5

Means with common letters are not significantly different (Mann–Whitney test; $p > 0.05$). SB = swim bladder.

The captured fish's number, total length, weight, Pankhurst's ocular index (OI), age (in years), and Fulton condition index (k) are summarized in Table 2. The biometric growth parameters analyzed in this study revealed that the females of the European silver eels were larger, heavier, and older than males (MWU test, $P \leq 0.05$).

Table 3. Descriptive statistics and estimated length–weight relationship parameters by sex for silver eels from the Shkodra/Skadar Lake, Albania.

Sex	n	L_{Tmin}	L_{Tmax}	W_{min}	W_{max}	Length–weight relation parameters				
						a	95% CI of a	b	95% CI of b	r^2
Male	61	35.0	47.5	66	188	0.000963	[0.0006 – 0.0040]	3.146	[2.764– 3.273]	0.898
Female	80	47.5	74.2	182	924	0.001414	[0.00052 – 0.00388]	3.059	[2.811 – 3.306]	0.887
Both	141	35.0	74.2	66	924	0.000808	[0.00062 – 0.00116]	3.195	[3.102 – 3.262]	0.978

n = sample size, L_T = total length [cm], W = weight [g], min = minimum, max = maximum, a = regression intercept, b = slope of regression line, CI = confidence interval, r^2 = coefficient of correlation.

The Length-Weight Relationship (LWR) for the analyzed silver eels was examined in three distinct forms: males separately, females separately, and combined, in order to understand their growth patterns.

The obtained data were presented in Table 3. For males, the relationship was described by W = 0.0008·L^3.146, with a coefficient of determination (r²) of 0.898, indicating a strong correlation between length and weight. The exponent $b > 3$ (3.146) suggests positive allometric growth, meaning that males gain weight more rapidly than length as they grow.

Females exhibited a somewhat different pattern, with W = 0.0012·L^3.059 and an r² = 0.887. The exponent b is slightly lower than that of males, but remains above 3, also reflecting positive allometric growth. The higher intercept a in females suggests that at the same length, females generally weigh more than males, consistent with the known sexual dimorphism in this species. When both sexes are combined, the LWR was W = 0.0009·L^3.195 with an excellent fit (r² = 0.978). This confirms the overall positive allometric growth model in European eels during the silver stage.

3.2. Anguillicolosis

Table 4. Age- and sex-specific prevalence of *Anguillicola crassus* in silver-stage European eels.

Age	No Examined	Positive Males	Positive Females	Total Positive	% of Total Sample	Prevalence %	% of Total Positives	95% CI (Lower)	95% CI (Upper)
4	15	13	0	13	10.64	86.67	25.00	62.10	100.00
5	27	8	5	13	19.15	48.15	25.00	29.10	67.20
6	20	5	6	11	14.18	55.00	21.15	33.70	76.30
7	22	4	5	9	15.60	40.91	17.31	21.10	63.70
8	20	0	3	3	14.18	15.00	5.77	3.20	37.90
9	13	0	1	1	9.22	7.69	1.92	0.20	36.00
10	13	0	2	2	9.22	15.38	3.85	1.90	45.40
11–14	11	0	0	0	7.80	0.00	0.00	–	–
Total	141	30	22	52	100%	36.88%	100.00%	–	–

Note: Prevalence (%) = (N positive / N examined) × 100; 95% confidence intervals calculated using the exact binomial method (binom.test).

During the examination for the potential presence of *A. crassus*, the prevalence of infection among European eels varied significantly across different age groups. The highest prevalence was observed in 4-year-old individuals, where 86.7% (13 out of 15) tested positive, all of whom were male. Similarly, the 5 and 6-year-old age groups exhibited high prevalence rates of 48.1% and 55%, respectively, affecting both sexes. A gradual decline was noted in the older age groups: 40.9% at 7 years, 15% at 8 years, and further decreasing to 7.7% and 15.4% in the 9 and 10-year-olds. No positive cases were found among individuals aged 11-14 years. Notably, the majority of positive cases in the younger age groups were males, while in the older groups, positive cases were scarce and predominantly females. Overall, out of 141 silver eels examined, 52 (36.9%) were infected, indicating an apparent decrease in parasite prevalence with age, with younger eels—particularly males—being the most affected.
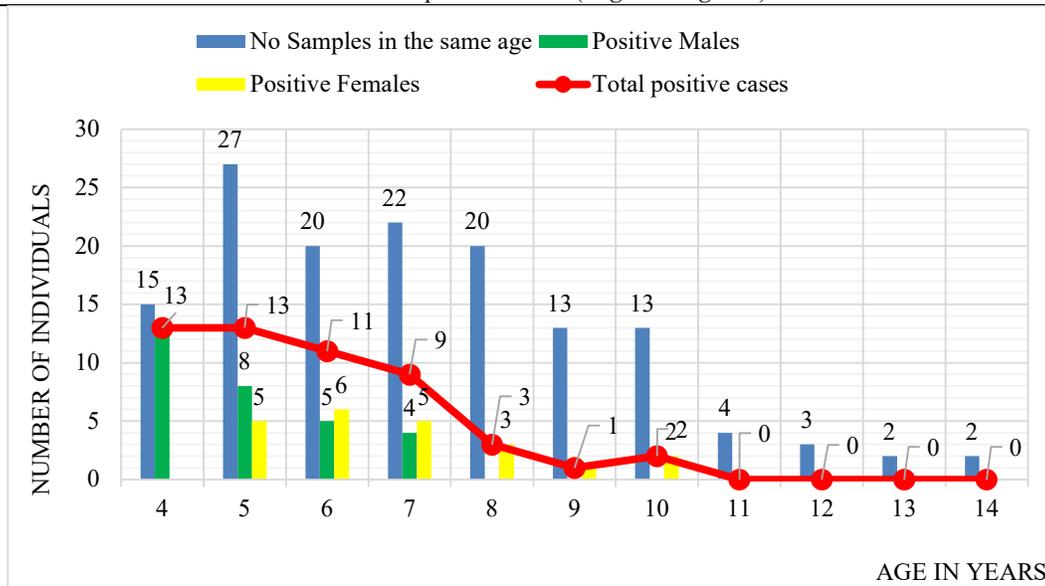
Figure 2. The distribution of positive cases by age, categorized by sex, and overall prevalence.

4. Discussion

This study examined 141 mature silver European eels captured from the transboundary Lake Shkodra/Skadar, which is divided between Albania and Montenegro in a ratio of 35% to 65% respectively [25]. This assessment is the first to evaluate the infection status of the parasite *Anguillicola crassus* in Albania, as there are no previously documented studies in the literature. Such a study has not been observed in the Montenegrin part of the lake either.

In comparison to our findings, which indicate a sex ratio of a slightly dominance of females among the silver eels in Lake Shkodra, the majority of published studies report skewed sex ratios. Some studies highlight a dominance of male European eels [26;27;28], while others indicate a predominance of female silver eels [29;30]. These comparisons suggest that the finding of this sex ratio may be coincidental. In fact, in this lake, approximately 75% of the captured eels weigh over 300g, leading to the consideration that a significant portion of these individuals may be females [31]. Further testing over two or three consecutive years is necessary to ascertain a more accurate ratio of migratory European eel individuals.

A statistically validated sexual dimorphism was identified in the length–weight relationship (LWR) between male and female specimens. The *b* values exceeded 3 (3.197 for males, 3.095 for females, and 3.148 overall), suggesting positive allometric growth, which aligns with the documented ranges for the European eel 2.26–3.67; [32;33]. This trend indicates sexual variations in body condition and may be associated with migration or reproductive maturation in silver eels.

Similar investigations in Lake Shkodra/Skadar have revealed differences in *b* values: Milošević & Mrdak [34] reported b = 2.96, whereas Milošević et al. [35] observed *b* = 3.12 for females and *b* = 2.12 for males. We believe that a realistic sampling of the migratory silver eel should be conducted in the Albanian section of Lake Shkodra/Skadar, as this region serves as the natural migration habitat for reproductive purposes. Additionally, direct capture using fishing gear (Fyke nets) installed along the length of the canal where the eel begins its migration to the sea (fish barrier) provides a more accurate orientation of the LWR values for the migratory silver eel.

The Fulton condition factor [*k*] exhibited minor differences between the sexes, with males averaging 0.167 ± 0.012 and females averaging 0.18 ± 0.018. In both genders, I demonstrated a weak negative correlation with length, suggesting a slight reduction in condition as body size increased. Low *k* values may indicate less favorable environmental conditions [36]. Similar trends were noted by Milošević et al. [35] in Lake Shkodra, where males experienced a slight decrease in *k*, while females showed a minor increase. Casalini et al. [37] reported a decline in *k*, length, and weight as eels approached their maximum silvering index. Fluctuations in *k* have been associated with environmental factors, food availability, sexual maturity, and seasonal changes, often increasing with body size [38].

The fat index, which indicates energy reserves, was greater in females (2.0) compared to males (1.7),

implying a better state of readiness for migration and reproduction. Visceral fat plays a crucial role in triggering reproductive migration to the Sargasso Sea [39;40].

4.1. Anguillicosis

In the study concerning the parasitic infestation by *Anguillicola crassus*, 36.9% of the 141 analyzed samples tested positive for the parasite. A similar prevalence of 39.71% was observed by Cakić et al. in 2002 [41] in Lake Ohrid, which is part of the same hydrological system as the Drin River basin, including Lake Shkodra/Skadar. The authors emphasized that peak infection levels occur during the winter. From 2016 to 2019, a study in the Neretva River estuary, Croatia, assessed eel populations in both freshwater and saltwater habitats. The results indicated a significantly higher infection rate of 41% in the freshwater of the Neretva River estuary (Eastern Adriatic Sea, Croatia), compared to only 7% in the saltwater lagoon of Parila [42]. In Greece, this parasite was first documented in 1996 [43], later confirmed by MacNamara et al. [44], who found a prevalence of 61.7% in the freshwater Lake Vistonis. The results suggest that A. crassus infestation rates may vary with the seasons, even within the Shkodra/Skadar Lake region. Our study was preliminary and aimed to determine whether this parasite affects the freshwater ecosystem or if the environment remains free of A. crassus. A more precise assessment of the parasite's prevalence could be achieved through multiple samplings conducted over successive years in this basin.

5. Conclusions

This study represents the first investigation into the health status of European eels in transboundary Shkodra/Skadar Lake, which is shared between Albania and Montenegro. This lake is the only one that applies the commercial artisanal fishery of European eel in the Albanian freshwater basins. Biometric analyses reveal statistically significant differences in metrics such as length, weight, condition factor, and age. The nematode parasite *A. crassus* exhibited a positivity rate of 36.9% among the 141 samples collected for the study. The number of adult *A. crassus* found ranged from 1 to 5 per eel, with males showing a notably higher infestation rate of 48.4%, in contrast to 27.8% in females.

6. Acknowledgements

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