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PREVALENCE OF THE Anguillicola crassus PARASITE IN THE INTERNATIONAL MINHO RIVER

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Abstract

The European eel, *Anguilla anguilla* (Linnaeus, 1758), is vulnerable to infections by the parasitic nematode *Anguillicola crassus* Kuwahara, Niimi & Itagaki, 1974, mainly in freshwater ecosystems. The eel is a bioindicator species due to its benthic behaviour, predator, and life cycle. The parasite feeds on blood from the eel's swim bladder, causing damage to the walls and deterioration of this organ, reducing energy reserves, and affecting its migratory capacity for reproduction. Eels were captured at different sampling points divided into 4 areas of the international section of the Minho River in the following time periods: 1995-96, 2008-2011 and 2017-2021, through fyke nets and electric fishing sampling techniques. The objectives of this work were to analyze the dispersion and prevalence of *A. crassus* in the Minho River basin over time, infection rates and the eels condition. The prevalence levels found reach values close to 75% in some sampled locations and 99% of eels shown pathological signs of swim bladder infection. The nematode dispersal area increased since the early 1990s when its presence in the Minho River was first recorded.

Keywords: *Anguillicola crassus*. *Anguilla anguilla*. Parasitism. River Minho. Swimbladder infection.

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1 Introduction

The alien swim bladder nematode parasite *Anguillicola crassus* Kuwahara, Niimi & Itagaki, 1974 illustrates a critical example of a very successful and hostile colonizer (KUWAHARA; NIIMI; ITAKAKI, 1974; AUDENAERT et al., 2003) fish parasite that owns its introduction and geographic area expansion to anthropic activities (SIMON et al., 2018). It was first introduced in Europe in the early 1980s under uncontrolled intercontinental exchange of live Japanese eel, *Anguilla japonica*, for human consumption from Taiwan (KIRK, 2003; WIELGOSS et al., 2008). The parasite quickly disseminated among Western, Northern and Central Europe European eel, *Anguilla anguilla*, populations in inland and brackish coastal waters (WYSUJACK; DOROW; UBL, 2014). *A. crassus* found in the intercontinental trade of anguillid hosts the means to become a global invader in the last decades (KNOPF, 2006; LEFEBVRE et al., 2012). Endowed with high fertility, high tolerance, resistance, and survivability of the second-stage larvae (KENNEDY; FITCH 1990; BARRY et al., 2014) this indigenous East Asia parasite can infect all eel sizes, including glass eels (NIMETH et al., 2000), once eels become vulnerable to infection as soon as they start feeding in rivers or estuaries (KENNEDY, 2007). This nematode plays therefore a considerable role in the decrease of *A. anguilla* eel populations as a primary or additional stress factor (PALSTRA et al., 2007; SJÖBERG et al., 2009).

The nematode presents a complex and indirect life cycle, infecting obligatory several intermediate and paratenic hosts before reaching the final host, the eel (DE CHARLEROY et al. 1990; JOUSSEAUME et al., 2021). The parasite lodges in the final host's swim bladder, where it reproduces (KIRK, 2003; LEFEBVRE; CRIVELLI, 2004). Adult females expel the eggs (already L2 stage) into the eel's swim bladder lumen that hatch within the swim bladder or soon after leaving the swim bladder via the ductus pneumaticus and gut. The motile L2 larvae stimulate its own predation by intermediate hosts, namely, copepods, penetrating their digestive tract, and moulting into L3 stage larvae (MORAVEC; TARASCHEWSKI, 1988; DE CHARLEROY et al., 1990; KIRK, 2003; ROLBEICKI; ROKICKI, 2005). These intermediate hosts can then be directly consumed by the final host or by paratenic hosts that turn to be preyed on by the eels (KIRK 2003; LEFEBVRE et al., 2012). In the eel, the L3 larvae leave the gut and penetrate the swim bladder wall developing into L4 larvae and to the pre-adult form, entering then in the swim bladder lumen, where the adult nematode feeds on blood from the swim bladder vasculature system, reproduces, and the cycle begins all over again (NIMETH et al., 2000; KIRK, 2003; SZÉKELY et al., 2009).

The lack of resistance adaptations that the European eel presents to this nematode derived from a non-co-evolutionary interaction between the two species and from the participation of paratenic hosts in the transmission of the parasite in Europe (KIRK, 2003; TARASCHEWSKI, 2006). The two factors that lead to different humoral responses and higher susceptibility of *A. anguilla* (NAGASAWA; KIM; HIROSE, 1994; TARASCHEWSKI, 2006) allowing *A. crassus* to demonstrate a higher prevalence and intensity rates, longevity, survival, and reproductive output than the ones observed in *A. japonica* (KNOPF, 2006; MÜNDERLE et al., 2006; TARASCHEWSKI, 2006).

However, other diverse selective forces not related to the European eel might be acting on the nematode, namely, changes in the biotic and/or abiotic environment aspects. For example, the constrained living resources available in a parasited overloaded swimbladder originates a strong intraspecific competition that might lead to a faster exploitation of the host, increasing growth rates and evolutionary shortening of the life cycle duration. As well as negatively affect the parasite survivorship due to the density of conspecifics in one niche (WECLAWSKI et al., 2013).

Environmental factors, such as climate, may also explain the faster development of European *A. crassus* populations. Temperature and salinity play a key role in the nematode survival. Although being considered a freshwater species, this parasite can tolerate high salinities and be found in marine and hypersaline waters (GIARI et al., 2021). High salinity, on the other hand, may have a direct negative impact on *A. crassus* throughout its free-living stages by lowering egg hatching, larval survival, and infectivity, as well as indirectly by limiting the spectrum of viable intermediate or paratenic hosts (KIRK; KENNEDY; LEWIS, 2000; LEFEBVRE; CRIVELLI, 2004).

Even though salinity has been found to inhibit the parasite infection, high prevalence has been documented in eels from marine environments and estuarine sites with extremely high salinity (LOUKILI; BELGHYTI, 2007). Infection levels in ecosystems with identical salinity ranges also can vary greatly (GIARI et al., 2021). *A. crassus* native range is over 20°C for most of the year. In Central Europe, by contrast, temperatures seldom exceed 20°C, with 8 months or more below 10°C. As a result, cold-adapted European populations of *A. crassus* may have evolved to complete the developmental cycle faster in response to lower temperatures (WECLAWSKI et al., 2013).

Some authors have reported no adverse effects on the performing of European eels during the freshwater stage of their life cycle under normal conditions (KELLY; KENNEDY; BROWN, 2000; LEFEBVRE et al., 2013).

However, the parasite presents a capacity to exceed 90% prevalence over a 4-year period (KNOPF, 2006; LEFEBVRE et al., 2013). With the capacity to induce structural and inflammatory pathological damage (MOLNÁR, 1993; LEFEBVRE et al., 2012), *A. crassus* is able to impair gas deposition, feed on swimbladder tissue, cause wall thickening, inflammation, tissue degeneration, and fill the lumen with eggs, larvae and dead nematodes (SCHNEEBAUER; HANEL; PELSTER, 2016). Extra stressors, for example, hypoxia also have considerable effects on the swimbladder viability of infected eels and can raise mortality (GOLLOCK; KENNEDY; BROWN, 2005; LEFEBVRE; CONTOURNET; CRIVELLI, 2007). This will cause significant modifications in multiple tissues, especially in the swimbladder tissue, and a possible reduction of the eel viability in some cases (MOLNÁR, 1993; BRACAMONTE et al., 2021).

The consequences are several histopathological changes in the structure of this organ (VAN BANNING; HAENEN, 1990; MOLNÁR, 1994; WÜRTZ; TARASCHEWSKI, 2000), inflammatory reactions (dilatation of blood vessels, hemorrhages, accumulation of macrophages and granulocytes), fibrosis, local necrosis, hyperplastic and dysplastic processes in the epithelial tissue (proliferation and alteration in the shape and structure of the cells) (LEFEBVRE et al., 2002), reduced elasticity of the organ (BARRY et al., 2014), reduced swimming speeds (PALSTRA et al., 2007) and lowered resistance to environmental stressors (GOLLOCK; KENNEDY; BROWN, 2005). Repeated larval invasion originates oedemic and hyperplastic changes in the swimbladder wall as well as dead encapsulated larvae and disintegrated adult nematodes (MOLNÁR, 1993; WURTZ; TARASCHEWSKI, 2000).

Infections can represent a problem to *A. anguilla* by hindering metabolic processes dependent on gaseous cell activity (PELSTER, 2015) or by inhibiting the ability to effectively regulate body position within the water column (PALSTRA et al., 2007). This factor also indirectly affects reproduction efficiency, as the amount of energy available for reproduction decreases considerably (VAN GINNEKEN; MAES, 2005; PALSTRA et al., 2007). Sébert et al. (2007) and Sjöberg et al. (2009) hypothesized that if an individual does not enter deeper oceanic waters, the process of sexual maturation cannot be completed, once high hydrostatic pressure triggers an increase in pituitary-gonad axis activity, raising plasma levels of sex steroids.

Any decline in organ control is suggested to threaten the successful completion of transoceanic migration, spawning activity, and subsequent recruitment of the next generation (SZÉKELY et al., 2009; LEFEBVRE et al., 2013). Although *A. crassus* does not directly cause host death, its presence has been reported to decrease its reaction to external factors (KIRK, 2003; ROLBEICKI; ROKICKI, 2005; PALSTRA, 2007). Due the swimbladder function, the problems observed in the survival of the individuals are probably more severe during the oceanic migrations (WYSUJACK; DOROW; UBL, 2014).
The European eel is classified as "critically endangered" (JACOBY et al., 2015) and serves as both a predator and a prey species in a healthy aquatic ecosystem. It is also a high commercial value species with very high cultural and economic importance. Since the 1970s, there has been a continuous drop in glass eel recruitment to continental waters (ICES, 2013), raising worries about the species' long-term health (DEKKER, 2008). The causes that led to the collapse are yet unknown. However, among other factors, the introduction in the 1980s of the invasive *A. crassus* must be considered (BARRY et al., 2017). From a management standpoint, it is critical to improve our understanding of how infection intensity and recurrent exposure are connected to resource utilization in an ecosystem for the future management of this endangered species in Europe. *A. crassus* was reported in the Minho River case of study for the first time in 1995/96 (ANTUNES, 1999), but information on how the parasite disseminated in the river is rare, as only in 2005 this species was mentioned again in the Minho tributary (AGUILAR et al., 2005). The aim of this study is to analyze the dispersion and prevalence of the nematode in the Minho River basin over time, infection rates and the eels condition.

2 Material and Methods

2.1 Study Area

The Minho River is situated in the NW-Iberian Peninsula (SW Europe) and presents a hydrological basin of 17080 km^2. Born in Serra da Meira, in the province of Lugo (Spain), it extends approximately 300 km to the Atlantic Ocean and represents the natural north-western border between Portugal and Spain in the last 70 km of its domain. Although experiencing saltwater intrusion only in the first 25 km of its extension, the Minho River displays a tidal influence until 40 km upstream that comprises the approximately 23 km^2 estuarine area (SOUSA et al., 2008).

The Minho estuary comprises an area between the municipalities of Caminha to Valença, 40 km long and presents mesotidal characteristics with average tidal variation that oscillates at approximately 4 meters of amplitude. Similarly, saline concentrations vary with the tides and can reach about 35 (COIMBRA et al., 2005). Classified as a Natura 2000 site due to its ecological importance (SOUSA et al., 2008), and known to generally present good quality waters, the River Minho can reach a water temperature of approximately 21ºC in the summer months and 9ºC in the winter (COIMBRA et al., 2005). The maximum river flow (2500 $m^3.s^{-1}$) is connected to the intense periods of precipitation observed during winter/ early spring, has the minimum flow ($60^3.s^{-1}$) occurs during summer/early autumn, related with periods of drought (ANTUNES et al., 2012).

2.2 Sample Collection

Samplings were performed throughout several points of the international zone of the Minho River divided in four areas: ZMI – marine influence area with tidal differences in salinity; ZT – transitional area with influence of salinity at low flows and spring tides; ZFW – freshwater area; ZTr – tributaries area (Figure 1). Three time periods were considered with 18 samplings sites in 1995/96 (N= 362), 16 sampling sites between 2009 and 2011 (N= 371) and 8 sampling sites between 2017 and 2021 (N= 392), through fyke nets (10 mm mesh, 7 m in length with two openings in funnel shape) in Minho River during the year and electric fishing during autumn and spring in tributaries.

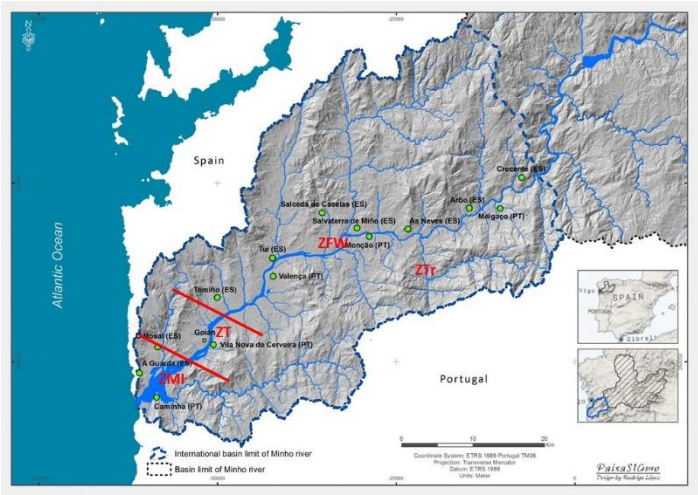

Figure 1. Minho River international section and eel sampling areas. ZMI – marine influence area with tidal differences in salinity; ZT – transitional area with influence of salinity at low flows and spring tides; ZFW – freshwater area; ZTr – tributaries area.

Fish died with an anaesthetic overdose. Total body length (0.1cm) and body weight (0.1g) were recorded. The swimbladders were removed and examined, counting the number of *A. crassus* in the lumen. The developmental states, L3, L4, pre-adult and adults, were identified (MORAVEC; TARASCHEWSKI, 1988; DE CHARLEROY et al., 1990; LEFEBVRE; CONTOURNET; CRIVELLI, 2002), and the number of individuals in each state was recorded.

Some individuals of *A. crassus* were deposited at the Natural History Museum of the Iberian Peninsula (NatMIP – "Museu de História Natural da Península Ibérica"), Aquamuseu do Rio Minho, Vila Nova de Cerveira, Portugal.

2.3 Swimbladder Degenerative Index (SDI)

The health state of the swim bladder of eels collected between 2017 and 2021, infected or not, was assessed and the organ was examined macroscopically to access its Swimbladder Degenerative Index (SDI) score (LEFEBVRE; CONTOURNET; CRIVELLI, 2002). The SDI score is determined by adding the scores obtained for the three criteria analyzed and can range from 0 (no pathological signs observed) to 6 (extremely damaged). Each of the criteria receives a score between 0 (no degradation), 1 (moderate degradation) or 2 (severe degradation). The first criterion to access focuses on the transparency-opacity of the swimbladder wall, with a transparent-yellowish colouration assigning a normal swimbladder (value 0).

When reading is not possible (total opacity observed), the value given was 2, and all intermediate cases by the value 1. The presence of pigmentation and exudate instead of gas in the swimbladder lumen was the second criterion to examine. In the presence of both pigmentation and exudate (dead worms, erythrocytes, decaying swimbladder tissue, eggs and L2 stage of *A. crassus*) was signed the value 2. Value of 0 for no pigmentation and no exudate, and value 1 to those that showed either pigmentation or exudate. The last criterion addressed the thickness of the swimbladder wall. Normal/thin-walled swimbladders (less than 1 mm) were classified with the value 0. The severely affected swimbladders with little or non-lumen left (more than 3 mm thick wall) were classified with the value 2. Value 1 was used in all other cases (LEFEBVRE et al., 2011).

2.3 Data Analysis

Prevalence (the percentage of parasitized eels), intensity (the number of parasites per infected eel) and abundance (the number of parasites per total eel number) were calculated for the sampling periods (BUSH et al., 1997). The Kruskal-Wallis analysis was applied to test differences in prevalence, intensity and abundance among sampling periods and areas, which were not normally distributed and the Dunn's post hoc test was applied in order to determine differences among groups. The indicator of general well-being and growth of fish, the Fulton's condition factor: $K = 100 \times [W\ (g)/TL^3\ (cm)]$ was calculated. Linear regression was performed to verify the relationship between intensity and condition factor (K) for all sample periods and SDI with infected eels and the number of parasites in swimbladder for the period 2017/21. Statistical analyses were carried out in PAST software, version 3.25 (HAMMER; HARPER; RYAN, 2001).

3 Results

During the three periods of investigation, a total of 1125 eels were examined, from these, 617 were infected with *A. crassus* and 508 did not present the parasite. The eels length ranged from 6.6 to 86 cm and their weight ranged from 0.3 to 1378 g.

The prevalence of parasites among all samples was 58.6 %, with the lowest values obtained in 1995/96 period (30.7 %) and increasing in the following periods (2009-11; 2017-21) to a similar order of magnitude (68 %, 63 % respectively (Table 1)). While in the 1995/96 period seven sampling points showed no infection in eels (1 in ZFW and 6 in ZTr), in later periods all sampling stations revealed the presence of infected eels. The mean abundance was 2.9 ± 2.1 parasites and the mean intensity of *A. crassus* in parasitised eels was 3.3 ± 4.5. The mean intensity of infection range from 2 to 11 parasites per infected eel and a maximum of 25 adult parasites and 71 larvae were found in the eels. Highest values of intensity and abundance were registered in ZMI zone in 2009/11 and 2017/21 (10.9; 6.6 and 6.6;6.6, respectively).

The mean intensity (H_c = 1.684, df = 2, p > 0.05) and the mean abundance (H_c = 2,131, df = 2, p > 0.05) did not differ significantly among the three periods which was not the case with the prevalence (H_c = 14.59, df = 2, p < 0.05) and Dunn's post hoc test revealed significant differences between 1995/96 period and the other two times sampling periods (2008/11 and 2017/21).

Considering the 2009/11 and 2017/21 sampling periods significantly differences among fishing areas were found for infection intensity (H_c = 27.08, df = 3, p < 0.05) and Dunn's post hoc test revealed significant differences between freshwater area (FW) and transition zone (ZT) and marine influence area (ZMI) as well as between tributaries zone (ZTr) and transition zone (ZT).

Abundance and intensity were not correlated with eel length (p > 0.05) for total sample.

No significant difference in K (t = 1.6213, df = 774, p > 0.05) considering infected and uninfected eels was found. No significant relationship was observed between parasite intensity and K (F= 2.12, p > 0.05).

In the period 2017/21 only 1% of the eels had no swimbladders pathological signs (SDI=0), 79% had moderate damage (1≤SDI≤3) and 20% had severe damage (SDI>3) (Figure 2). The mean SDI of infected eels was 2.51±1.12 and was significantly higher with the eel size (F = 4.65, p < 0.05) and with the number of parasites in swimbladder (F = 19.87, p < 0.05) (Figure 3).

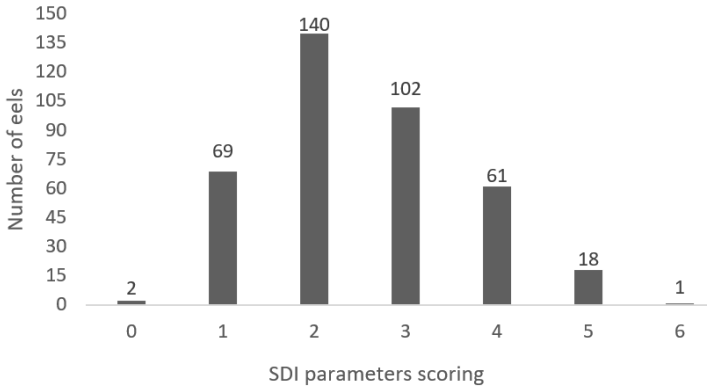

Figure 2. Frequency distribution of the swim bladder degenerative index (SDI) in 2017/21 period.

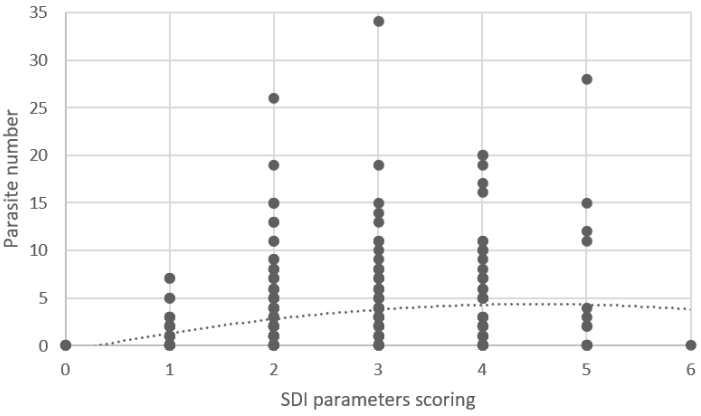

Figure 3. *A. crassus* number throughout the several the swimbladder degenerative index (SDI) stages found in 2017/21 period.

Table 1. *Anguillicola crassus* infection in international Minho River in 1995/96, 2009/11 and 2017/21 periods. Sampling areas, number of eels, total length (TL) and length range, eel condition factor (K), prevalence, intensity and intensity range, and abundance of the parasite. * SD not available (according to Antunes, 1999); ** according Braga (2011).

Period	Sampling area	N of eels	Mean TL (cm ± SD)	Length range	K	Prevalence (%)	Prevalence (%)	Mean Intensity	Intensity range	Abundance
1995/96*	ZFW	19	37.2*	19 - 62	0.19	31.6	30.7	2*	1 - 4	0.6
	ZTr	343	24.8*	7 - 60	0.20	29.7		3.7*	1 - 25	1.1
2009/11**	ZFW	67	16.7 ± 7.3	8.4 – 36.2	0.16	68.2	67.9	2.8±1.8	1 - 4	2.6
	ZTr	154	20.0 ± 8.0	6.6 – 38.2	0.15	59.1		2.1±1.4	1 - 7	1.4
	ZT	121	36.4 ± 11.9	10 - 78	0.16	74.7		4.0±3.0	1 - 15	3.1
	ZMI	33	33.0 ± 8.2	22.3 – 51.8	0.16	69.7		14.7±23.7	1 - 71	6.6
2017/21	ZFW	64	17.7 ± 2.9	12.4 – 25.0	0.11	54.7	63.1	3.1±2.9	1 - 13	1.7
	ZTr	33	27.3 ± 6.9	12.6 – 39.0	0.15	57.6		3.4±4.7	1 - 4	2.0
	ZT	276	40.1 ± 12.6	9.2 – 86.0	0.17	67.5		5.0±5.0	1 - 25	3.2
	ZMI	11	32.5 ± 14.0	14.1 – 64.0	0.16	72.7		9.1±9.0	1 - 17	6.6
All	All	1121	28.6 ± 8.5	6.6 – 86.0	0.16	58.6	58.6	5.0±4.0	1 - 71	2.9

4 Discussion

The date of introduction of parasite *A. crassus* in Minho River is uncertain. In the international section of the river samplings done in 1989/90 did not reveal any infection in eels, and the first records of infection date from 1995/96, with evidence of recent parasite establishment as clean areas were found and the highest prevalence was registered in areas close to the wild yellow eel stocking ponds coming from Spain, Tunisia and Morocco as well as farmed eels from Netherlands on which some may have escaped. Baruš, Moravec and Prokeš (1999) suggest that the fast spreading of *A. crassus* along European rivers is in general a consequence of importations and stocking of eels.

A gradual increase in prevalence was expected upstream due to decrease of salinity (HEITLINGER et al., 2009; WYSUJACK; DOROW; UBL, 2014), however that was not found. Low population density might also explain the fluctuations in prevalence, since according to Heitlinger et al. (2009), higher population densities allow high prevalence levels. Prevalence increased in the 2009/11 to 68 % and did not change significantly in the following period. Stable prevalence values have been reported for Vortsjarv lake (65%) (KANGUR et al., 2010) and Neusiedler See and Balaton Lake (60 %) (SCHABUSS et al., 2005).

High prevalence was found in marine influence zone (ZMI) but the fact that it is an estuarine brackish water area, with constant changes in salinity, the parasite may not be directly affected by this chemical parameter of the water. In the Comacchio Lagoon the percent of infected eels was significantly lower with increasing salinity (GIARI et al., 2021) while in estuaries prevalence values above 30% were reported (HERMIDA; SARAIVA; CRUZ, 2008; NETO et al., 2010). As there is no consensus on the influence of salinity other aspects should be considered in investigating *A. crassus* success and dispersion (GIARI et al., 2021).

In Minho River the eel's food is mainly composed by fish, crustaceans (particularly in estuarine area), insect larvae and molluscs. Paratenic fish hosts checklisted by Baruš, Moravec and Prokeš (1999) present are *Tinca tinca*, *Carassius auratus*, *Cyprinus carpio* and *Gasterosteus aculeatus*. The parasite *A. crassus* needs crustaceans as intermediate hosts and different species of copepods and ostracods are described (LEFEBVRE et al., 2012). The abundance of intermediate host marine copepods may allow the establishment and spread of the parasite in estuaries and saline lagoons (KIRK; KENNEDY; LEWIS, 2000; KENNEDY, 2007). The differences found in infection intensity between FW - ZT and FW - ZMI as well as ZTr – ZT may reflect differences in the diversity and abundance of intermediate hosts, which should be identified in the future.

The influence of the parasite on the eel body condition is different according to the authors. A positive relation was observed in Esva River when considered adults parasites (COSTA-DIAS et al., 2010) while several studies documented no effects of *A. crassus* on body condition (NETO et al., 2010; DENNY; DENNY; PAUL, 2013). In the present study, we found no change in the body condition of eels when comparing infected and uninfected eels. In the 2017/21 period only 1% of the eels had no swim bladders pathological signs (SDI=0). There is no correlation between the eel´s length and the percentage of infected eels, has observed by other authors (KOOPS; HARTMANN, 1989; BARRY et al., 2014).

Almost all the eels of the sampling area show pathological signs of infection in their swim bladder (99.0%). Though most eels are moderately affected (79.0%), a significant proportion (20.0%) exhibits profound ultrastructural changes that no doubt impair the swim bladder functions. Host size might be the most contributing factor in explaining variation in the swim bladder degenerative index. An increasing general trend of damage is observed as the eel size rises (LEFEBVRE; CONTOURNET; CRIVELLI, 2002).

The damage observed in the swim bladder, and the parasite count of lumen worms shown a non-linear relationship, and, in some cases, no sign of degeneration was found, despite the harbouring of living nematodes. Several infection events are necessary to observe pathological changes in the swimbladder. In less severe cases, the lack of parasites may be caused by an insufficient food supply (destruction of the swim bladder capillary system on which lumen worms actively feed), an unsuitable habitat for larval development or acquired immune response from the host (VAN BANNING; HAENEN, 1990; WÜRTZ; TARASCHEWSKI, 2000; LEFEBVRE; CONTOURNET; CRIVELLI, 2002). Regardless of the cause, severely affected eels can be expected to provide an unfavorable environment for the invasion and survival of *A. crassus* (SZÉKELY et al., 2009). As well as the absence of parasites does not discard the possibility of the eel been repeatedly infected and severely affected in the past (LEFEBVRE et al., 2013).

In heavily infected eels, changes of reaching the Sargasso Sea are very reduced or even zero as their swim bladders are destroyed and the energy reserves of the individuals are probably too low (KENNEDY, 2007) representing a possible negative influence on migratory capacity. Although *Anguillicola crassus* in the European eel tends to stabilize within infected areas, it may be simply the reflect of eel mortalities or accumulation of damages in the infected organ (LEFEBVRE; CRIVELLI, 2004).

When compared with the oldest data available, *A. crassus* population in the international Minho River keeps increasing and establishing in new river sites. The practice

of translocating eels that accumulate in the first dam (ZFW) to tributaries (ZTr) has been ongoing for some years, where infection intensity is lower. Further studies are needed to monitor the prevalence status as well as the hosts of the *A. crassus* in the Minho River.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

L. Pereira: Conceptualization, Formal analysis, Investigation, Methodology, Writing - original draft preparation. C. Braga: Investigation, Writing - review & editing. A. Moura: Investigation, Writing - review & editing. C. Antunes: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing - review & editing.

DECLARATION OF INTEREST

The authors disclose that they have no known competing financial interests or personal relationships that could have appeared to influence the study reported in this manuscript.

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