The Isopod Parasite *Ceratothoa oestroides* (Cymothoidae) in European Sea Bass (*Dicentrarchus labrax*): Estimation of Initial Reproductive Maturity and Fecundity

Parazitski izopod Ceratothoa oestroides (Cymothoidae) u brancina (Dicentrarchus labrax): procjena početne reproduktivne zrelosti i fekunditeta

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https://doi.org/10.17818/NM/2026/2.1
UDK 591.69:639.3(262)
Original scientific paper / *Izvorni znanstveni rad*
Paper received / *Rukopis primljen:* 1. 6. 2026.
Paper accepted / *Rukopis prihvaćen:* 6. 7. 2026.

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Abstract

Ceratothoa oestroides **(Cymothoidea, Isopoda) is a crustacean parasite that primarily affects European sea bass (*Dicentrarchus labrax*) in Mediterranean aquaculture. The study aimed to estimate first reproductive maturity and fecundity using degree days (DD). Samples were collected from farmed European sea bass in the central Eastern Adriatic Sea between July 2017 and November 2022. Data were collected from six generations of European sea bass aged < 1 year during vaccination, with water temperatures of 13-25°C and DD of 1080-6869. Parasites were found in all samples, with 70.8% containing mature females. Samples of fish with immature female parasites (29.2%) were recorded at DD values ranging from 1080 to 3330. Mature females were recorded at DD values from 1873 to 6869. The proportion of mature females in samples ranged from 1% to 42%. A total of 2281 mature females were examined, with fecundity ranging from 7 to 327, averaging 91. Both DD and host size influenced parasite size, age at first maturity, and reproductive output. Fecundity increased significantly with DD, indicating a link to age and size. Understanding the reproductive biology of this parasite can enhance sustainable aquaculture practices and provide insight into how aquaculture may impact nearby wild fish populations.**

KEY WORDS

Dicentrarchus labrax
Ceratothoa oestroides
parasite
fecundity
principal component analysis (PCA)
degree days

Sažetak

Ceratothoa oestroides (Cymothoidea, Isopoda) je jednakonožni nametnik koji prvenstveno ima veliki utjecaj na proizvodnju brancina (Dicentrarchus labrax) u akvakulturi Sredozemlja. Cilj studije bio je procijeniti prvu reproduktivnu zrelost i plodnost s pomoću stupnjeva dana (DD). Uzorci uzgajanog brancina prikupljeni su u srednjem Jadranu između srpnja 2017. i studenoga 2022. Podaci su prikupljeni od šest generacija brancina starosti < 1 godine tijekom cijepljenja, s temperaturama vode od 13 do 25°C i DD od 1080 do 6869. Paraziti su pronađeni u svim uzorcima, od kojih je 70,8% sadržavalo zrele ženke. Uzorci riba s nezrelim ženkama parazita (29,2%) zabilježeni su pri DD vrijednostima u rasponu od 1080 do 3330. Zrele ženke zabilježene su pri DD vrijednostima od 1873 do 6869. Udio zrelih ženki u uzorcima kretao se od 1% do 42%. Ukupno je pregledana 2281 zrela ženka, fekunditet je bio od 7 do 327, u prosjeku 91. DD i veličina domaćina utjecali su na veličinu nametnika, dob prve zrelosti i reproduktivni učinak. Fekunditet se značajno povećao s DD-om, što ukazuje na vezu s dobi i veličinom. Razumijevanje reproduktivne biologije ovog parazita može poboljšati prakse održive akvakulture i pružiti uvid u to kako akvakultura može utjecati na obližnje populacije divljih riba.

KLJUČNE RIJEČI

Dicentrarchus labrax
Ceratothoa oestroides
nametnik
fekunditet
PCA biplot
stupanj dani

* Corresponding author

1. INTRODUCTION / *Uvod*

Cymothoidea parasites infect both farmed and wild fish species [1-5]. Host selection depends on ecological factors, particularly fish habitats that facilitate interactions with swimming larvae (pulli II) [6]. Among these, *Ceratothoa oestroides* (Risso, 1827) is the most significant isopod affecting farmed marine fish in the Mediterranean. A pair of *C. oestroides* (male and female) resides in the fish's oral cavity, where they feed and complete their life cycle [7]. The parasite is a protandrous hermaphrodite; mature females attract males and prevent them from developing into females [8-10]. Female offspring develop in a marsupium until reaching the pulli II larval stages, after which they are released into the environment. The presence of eggs or larvae in the marsupium throughout all seasons indicates ongoing reproductive activity [11].

It causes significant losses in European sea bass (*Dicentrarchus labrax*) and moderate impacts on gilthead seabream (*Sparus aurata*) and meagre (*Argyrosomus regius*) aquaculture [12-14]. Mortalities among fry and fingerlings up to 20 g range from 10% to 50% [12-13, 15]. Additionally, losses in European sea bass and meagre include a 20% reduction in growth and a decrease in market value due to jaw deformities [12-14, 16-17].

Given the impact of this parasite on European sea bass farming, it is concerning that our understanding of how temperature affects development, lifespan, reproductive maturity, brood number per female, and fecundity in relation to size and age remains incomplete and fragmented. Previous studies lacked sufficient observation periods for females to reach reproductive maturity [10, 16]. Regarding fecundity, reports include 40-396 eggs from 258 gravid females [11] and 450-550 pulli II from 50 females [12], though details on fish or parasite weight and length are lacking. In fish weighing 8-50 g, fecundity was lower, with 40-124 pulli I and pulli II [15]. These notable differences likely reflect variation in female age and size, as larger, older females generally produce more offspring [18].

As mariculture expands, understanding parasite biology is crucial for developing new control tools and for efficiently planning measures [19, 20]. Field data on *C. oestroides* infections in wild fish are limited, but aquaculture systems enable the collection of large amounts of data on parasites, fish, and the environment, which are harder to obtain from wild populations [13]. Data collection on farms is easiest during harvest and routine activities such as vaccination.

Prevention through good practices, such as removing dead fish, age-group separation, and monitoring, is the most common measure used to control parasites in fish farms [21]. These measures are particularly important given that few antiparasitic agents are effective against *C. oestroides*, continuous administration may induce resistance, and reinfection can occur rapidly [19, 22]. Mechanical removal has been shown to be effective; the parasite is large, and only one pair parasitises an individual fish, allowing removal during vaccination [15, 22-23].

In the context of climate change and rising sea temperatures, farmers require tools to predict diseases caused by crustacean parasites that are linked to environmental temperature shifts. Treatment strategies should be aligned with the parasite's reproductive cycle. Estimating the timing of parasite maturation can enhance disease management on farms by enabling treatment intervention before the parasite reaches reproductive maturity. This study aims to estimate the timing of initial sexual maturity and fecundity of *C. oestroides* in correlation to degree days (DD) under farm conditions, during the first breeding year in European sea bass.

2. MATERIALS AND METHODS / *Materijali i metode*

The study was conducted at four fish-farming sites operated by a single company with a history of *C. oestroides* infection (Figure 1) situated in the middle part of the Eastern Adriatic Sea from July 2017 to November 2022. These farms implement integrated parasite management, including separating fish generations, removing infected fish during vaccination, and antiparasitic treatments. All sites were equipped with 25-metre diameter floating net cages with a volume of 5,000 m^3. For the purposes of the research, only data on untreated European sea bass were included. The sea temperature was measured at a depth of 8 metres at each farm.

Degree-days (DD) were used as a measure of thermal time and calculated as the cumulative sum of daily sea-water temperatures (°C) from the start of the farming period at sea cages:

$DD = \Sigma T_i$, where T_i is the mean daily sea-water temperature (°C) on day i.

The prevalence of *C. oestroides* in the fish population was visually assessed during the vaccination procedure. The parasite prevalence in each sample was determined [24] according to the following formula

$$\text{Prevalence} = a/(a+b) \times 100$$

Where a = number of individuals in the sample with parasites; b = number of individuals in the sample without parasites.

Vaccination was performed before the fish reached one year of age. At all farms, fish were vaccinated at approximately 20 grams body weight.

All fish infected with *C. oestroides* were removed from the cages. Parasitised fish were euthanised with an overdose of anaesthetic (Aquacen benzocaine 200 mg/ml, Cenavisa, S.L., Spain). From each cage, a random sample of 80-100 parasitised fish was collected for further analysis and kept on ice. In the laboratory, the total length (TL fish) of *D. labrax* was measured, and parasites were carefully removed from the oral cavity with tweezers. *C. oestroides* was identified following a previous study [25]. The lengths of the female and male isopod parasites from the anterior end of the head to the posterior end of the pleotelson (TL parasite) were recorded. Female parasites carrying pigmented eyed larvae in the marsupium were classified as sexually mature [10]. This method is not entirely accurate because it excludes ovigerous females (Figure 2). However, it was chosen because it represents the final stage of development in the marsupium and is easier under farm conditions. To assess female fecundity, pigmented-eyed larvae were removed from the marsupium and counted.

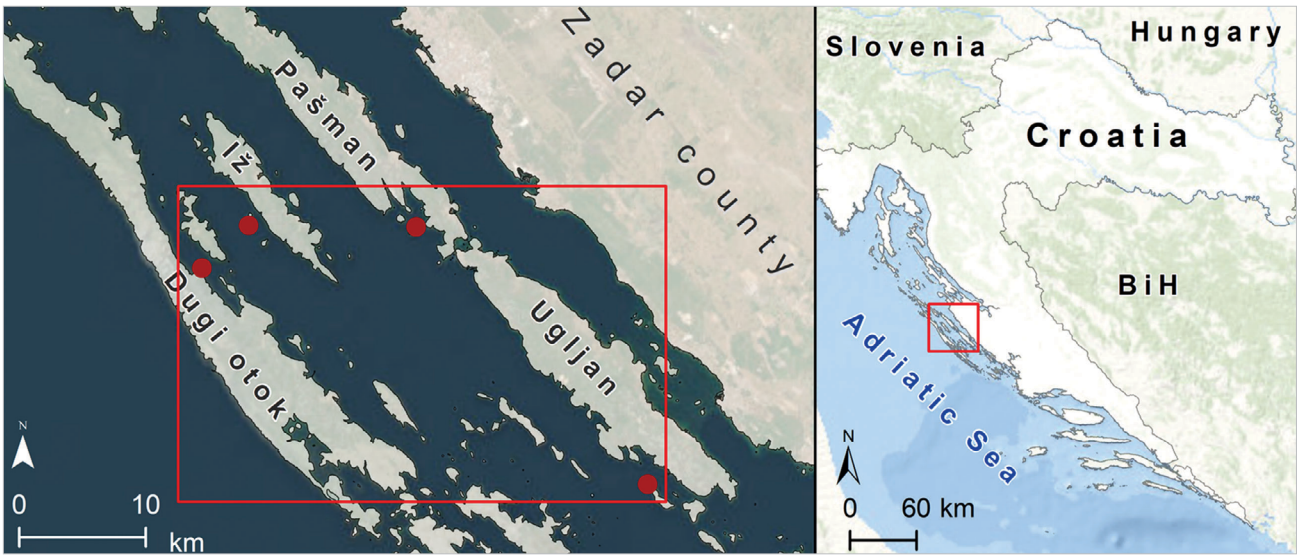


Figure 1 Locations of the sea-cage farms in the central Eastern Adriatic Sea, Croatia

Slika 1. Lokacije uzgajališta u morskim kavezima u središnjem dijelu istočnog Jadrana, Hrvatska

Source: Authors' own work based on Esri ArcGIS Online basemaps (World Imagery and World Topographic Map), © Esri and respective data providers, https://www.arcgis.com, accessed August 2026. [36]



Figure 2 *Ceratothoa oestroides* (Risso, 1826), immature female, ovigerous females, and female with pigmented eyed larvae in the marsupium

Slika 2. Ceratothoa oestroides (Risso, 1826): nezrela ženka, ovigerne ženke i ženka s ličinkama u marsupiju

Source: Photograph by Slavica Čolak

2.1. Data analyses / *Analize podataka*

The comprehensive database contains 233 samples from 233 cages, totalling 22,817 fish with parasites: 2,281 fish had a pair of parasites, including a mature female, and 20,536 fish had a pair with an immature female. Descriptive statistics were computed for both datasets: mature and immature parasite pairs. The data on parasite fecundity were statistically analysed in detail. The data were tested for normality using the Kolmogorov-Smirnov test. The descriptive statistics are presented in tables and box-and-whisker plots generated using IBM SPSS Statistics. The box represents the interquartile range (IQR; 25th–75th percentile), with the central line indicating the median. Whiskers extend to the most extreme values within 1.5 × IQR from the quartiles. The outliers (1.5–3 × IQR) are shown as circles, while extreme outliers (>3 × IQR) are indicated by asterisks. The correlation, principal component analyses, and descriptive statistics were conducted using SPSS and Origin Pro, with Python programming added.

3. RESULTS / *Rezultati*

A total of 48 765361 European sea bass from 233 cages were visually inspected for the presence of *C. oestroides* during vaccination at sea temperatures from 13-25°C. A summary of the sampling effort across years is presented in Table 1.

Table 1 Sampling effort of *Ceratothoa oestroides* in farmed European sea bass, Eastern Adriatic Sea, 2017-2022. For each year, the table shows the number of sampled cages (n cages), the number of visually inspected fish (n fish), the number of removed fish with parasites (n parasitised fish) and the number of sampled fish with parasites (n sampled fish)

*Tablica 1. Opseg uzorkovanja parazita Ceratothoa oestroides pri uzgajanom brancinu u istočnom Jadranu, 2017. – 2022. Za svaku godinu prikazani su: broj pregledanih kaveza (*n* kaveza), broj vizualno pregledanih riba (*n* riba), broj uklonjenih riba s parazitima (*n* parazitiranih riba) te broj uzorkovanih riba s parazitima (*n* uzorkovanih riba)*

Year	n cages	n fish	n parasitised fish	n sampled fish
2017	33	6414768	64284	3365
2018	71	12292636	83054	8779
2019	81	14651302	133202	6891
2020	15	3266994	30866	1176
2021	14	4980634	16106	1038
2022	19	7159027	20237	1568
Total	233	48765361	347749	22,817

Parasites were found in all 233 samples (cages), with an overall prevalence of 0.71% across all examined fish. The highest prevalence among the samples was 4.8%, and the lowest was 0.01%. The study covered a range from 1080 DD to 6869 DD. Parasite pairs with mature females were not present in all samples. Samples of fish hosting pairs of parasites with only immature females were collected within a range of 1080-3330 DD. The descriptive statistics for parasitised fish

and pairs of parasites with immature females are presented in Table 2.

Parasite pairs with mature females were found in 70.8% of the samples in the range of 1873-6869 DD. The percentage of mature *C. oestroides* females in the samples ranged from 1% to 42%. A total of 2,281 mature females were examined, and the average fecundity was determined to be 91 (Table 3).

Descriptive statistics of parasitic pairs with mature female and male length, degree days (DD) and fecundity through the sampling years are presented in Figure 3.

There were no statistically significant differences in the distribution of degree days (DD), total length of fish (TL fish) with mature parasites, length of mature female and male parasites (TL parasite), and fecundity of parasites (log values) between sampling years.

Table 2 The descriptive statistics (Median, Average, Minimum-Min, Maximum-Max and standard deviation-STDEV) of sea temperature, degree day (DD), the total length of parasitised fish (TL fish) hosting parasite pair with immature female, and total length of immature female and male parasites (TL parasite)

Tablica 2. Deskriptivni statistički pokazatelji (medijan, sredina, min., maks. i SD) temperature mora, stupnjevi dana (DD), ukupne duljine parazitiranih brancina (TL riba) s parom parazita koji uključuje nezrelu ženku te ukupne duljine nezrelih ženki i mužjaka parazita (TL parazita)

	sea temperature °C	DD	TL fish (mm)	TL female parasite (mm)	TL male parasite (mm)
Median	21	3282	156	22	9
Average	20	3369	154	21	9
Min	13	1080	78	4	2
Max	25	6869	275	35	24
STDEV	3	1228	26	4	3

Table 3 The descriptive statistics (Median, Average, Minimum-Min, Maximum-Max and standard deviation-STDEV) of sea temperature, degree day (DD), total length of fish (TL fish) hosting parasite pair with mature female, length of mature female and male parasites (TL parasite), and fecundity of parasites

Tablica 3. Deskriptivni statistički pokazatelji (medijan, sredina, min., maks. i SD) temperature mora, stupnjevi dana (DD), ukupne duljine brancina (TL riba) s parom parazita koji uključuje zrelu ženku, duljine zrelih ženki i mužjaka parazita (TL parazita) te plodnosti parazita

	sea temperature °C	DD	TL fish (mm)	TL female parasite (mm)	TL male parasite (mm)	Fecundity of parasites
Median	20	4056	171	24	11	84
Average	19	4189	172	24	11	91
Min	13	1873	104	11	3	7
Max	25	6869	270	34	18	327
STDEV	3	1018	20	3	2	45

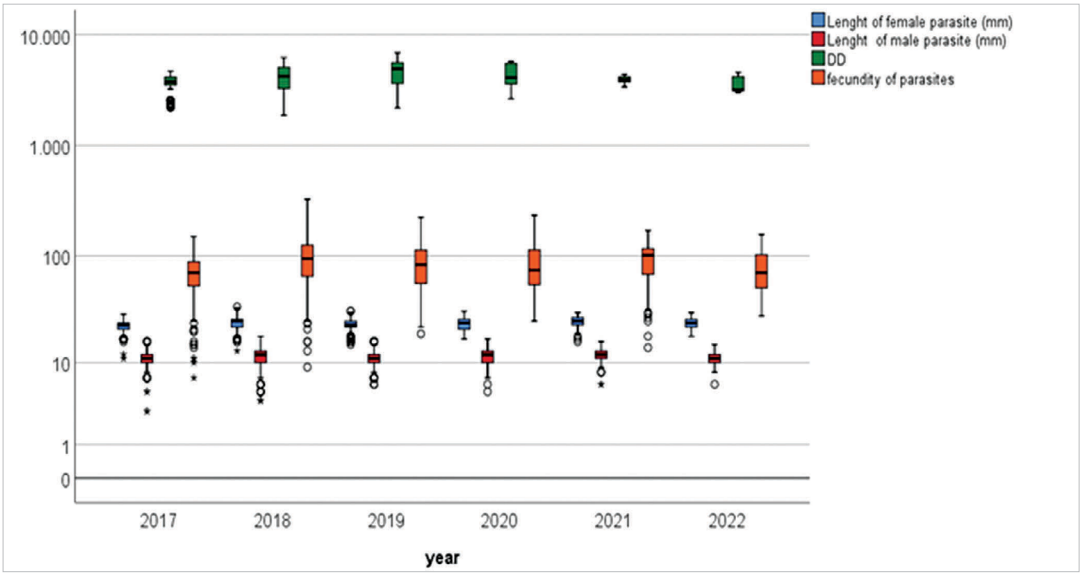


Figure 3 The descriptive statistics explaining the distribution of degree day (DD) in parasite pairs with mature female, length of mature female and male parasites (TL parasite), and fecundity of parasites (log values) over the sampling years

Slika 3. Raspodjela stupnjeva dana (DD) pri parovima sa zrelom ženkom, duljine zrelih ženki i mužjaka (TL parazita) te plodnosti parazita (log vrijednosti) po godinama uzorkovanja – deskriptivni statistički pokazatelji

Source: Author's own work using IBM SPSS Statistics

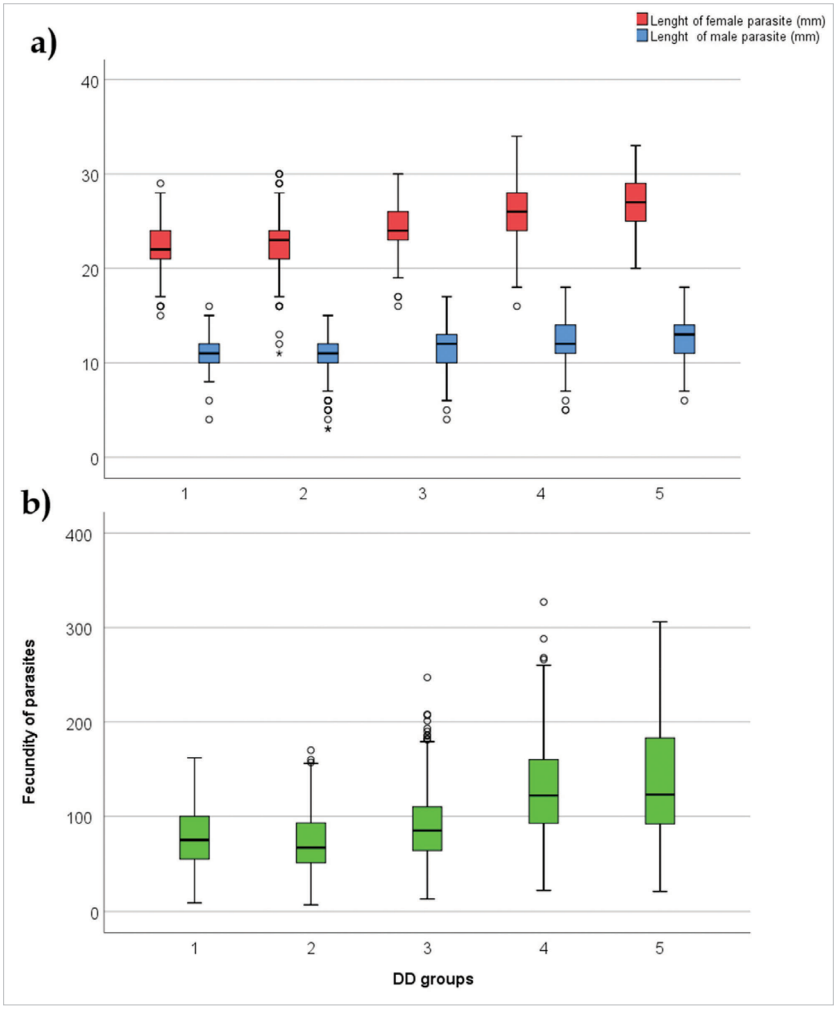


Figure 4 Descriptive statistics of parasite pair with mature female: a) total length of mature female parasite (mm) -red bars, and male parasite (mm)- blue bars; and b) the parasite's fecundity - green bars. Data are presented in 5 groups based on DD (DD ranges for the groups are as follows: group 1: 1,000-3,000; group 2: 3,000-4,000; group 3: 4,000- 5,000; group 4: 5,000-6,000; and group 5: 6,000-7,000. * Only one sample had DD less than 2000, so group 1 consists of DD values from 1,000-2,000

*Slika 4. Deskriptivni statistički pokazatelji parazitskog para sa zrelom ženkom: a) ukupna duljina zrele ženke (mm) – crveno, i mužjaka (mm) – plavo; b) plodnost parazita – zeleno. Podaci su prikazani u 5 skupina prema DD (rasponi: 1. 1.000 – 3.000; 2. 3.000 – 4.000; 3. 4.000 – 5.000; 4. 5.000 – 6.000; 5. 6.000 – 7.000). * Samo jedan uzorak imao je DD < 2.000 pa skupinu 1 čine vrijednosti od 1.000 do 2.000*

Source: Author's own work using IBM SPSS Statistics

Figure 4 presents variation in parasite pairs with mature female parameters: mature female parasite length (red) and male parasite length (blue) (Figure 4a), and fecundity (green) (Figure 4b), expressed as boxplots. The data are presented for the DD group across five different groups (clusters). Female parasite length generally remains around 24 mm (Median, Table 3), while their medians are slightly increasing with the increase of DD (Figure 4a).

Parasite fecundity, with a median of 84, exhibits the greatest variation, with longer whiskers indicating greater dispersion and occasional high values. It is important to note that fecundity significantly increases with DD (Figure 4b) relative to parasite length (Figure 4a), especially in DD groups 4 and 5, where DD ranged from 5,000 to 7,000 (Figure 4b).

3.1. Correlation and Principal Component Analysis / *Korelacijska analiza i analiza glavnih komponenata (PCA)*

The tested parameters were not normally distributed, as indicated by the Kolmogorov-Smirnov test. Accordingly, Spearman correlation analysis was applied to the data. The analysis revealed several significant relationships among environmental, host, and parasite variables, as shown in Figure 5. DD showed positive correlations with all biological parameters, including fish length, female parasite length, male parasite length, and fecundity (Figure 5). Fish length exhibited moderate positive correlations with female parasite length, male parasite length, and fecundity. Strong positive correlations were found between female parasite length and fecundity, and between male parasite length and fecundity. Additionally, female and male parasite lengths were strongly correlated, suggesting synchronised growth between the sexes. Overall, degree days and host size were identified as the main factors influencing parasite length and reproductive output. These results clearly illustrate the strong biological associations within the host-parasite system and are summarised in Figure 5.

The PCA biplot presents the ordination of environmental and biological variables based on Principal Component Analysis (PCA), showing the relationships between the previously defined DD groups and measured variables (Figure 6). The first principal component (PC1) explains 48.1% of the total variance,

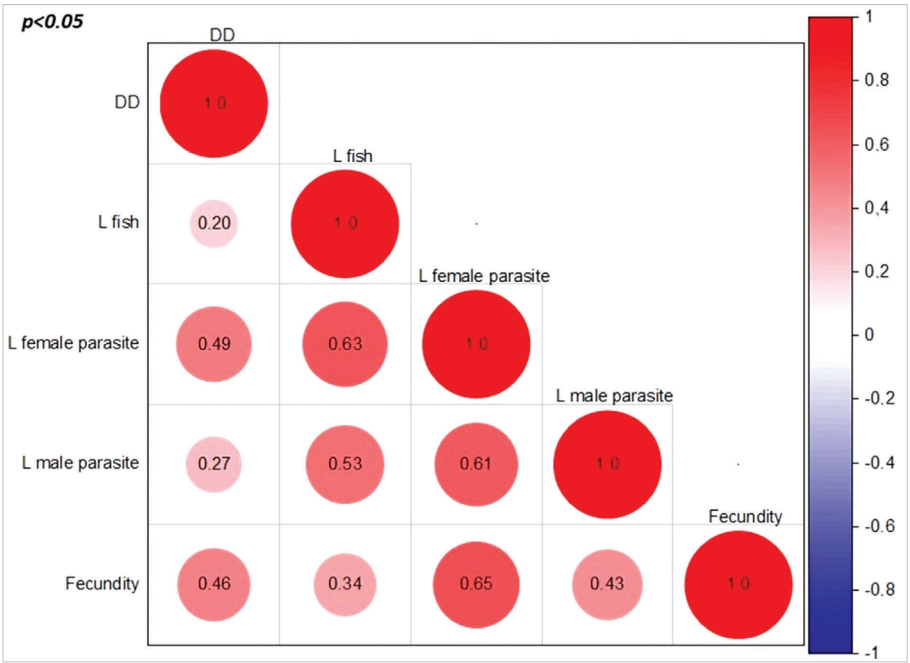


Figure 5 Correlogram of determined parameters representing Spearman's correlations between determined parameters with a significant level ($p < 0.01$)

Slika 5. Korelogram utvrđenih parametara s prikazom Spearmanovih korelacija između parametara na razini značajnosti ($p < 0,01$)

Source: Author's own work using IBM SPSS Statistics

while the second principal component (PC2) accounts for 17.2%. Together, PC1 and PC2 explain a cumulative 65.3% of the total variability in the dataset, indicating a significant representation of the original data (Figure 6). The variables plotted as blue arrows indicate their direction and strength of correlation with the principal components. The arrows for fecundity of parasites, length of male parasite, length of female parasite, and length of fish are aligned mainly with PC1, suggesting that these variables are strongly positively correlated and contribute most to PC1 (Figure 6), as it was previously shown also by correlation analysis (Figure 5). The DD variable shows positive loadings on the PC1 plot and is correlated with parasite fecundity, male parasite length, female parasite length, and fish length (Figures 5 and 6). The length and direction of the arrows reflect the magnitude and direction of correlations: longer arrows indicate stronger correlations with the principal components. DD groups are represented by different symbols and colours (red points cluster represents DD 1 group, yellow points cluster represents DD 2 group, green points cluster represents DD 3 group, blue points represent the cluster of DD 4 group, and purple symbol plus represents the cluster of DD 5 group). Although group ellipses partially overlap, a clear separation is observed along PC1,

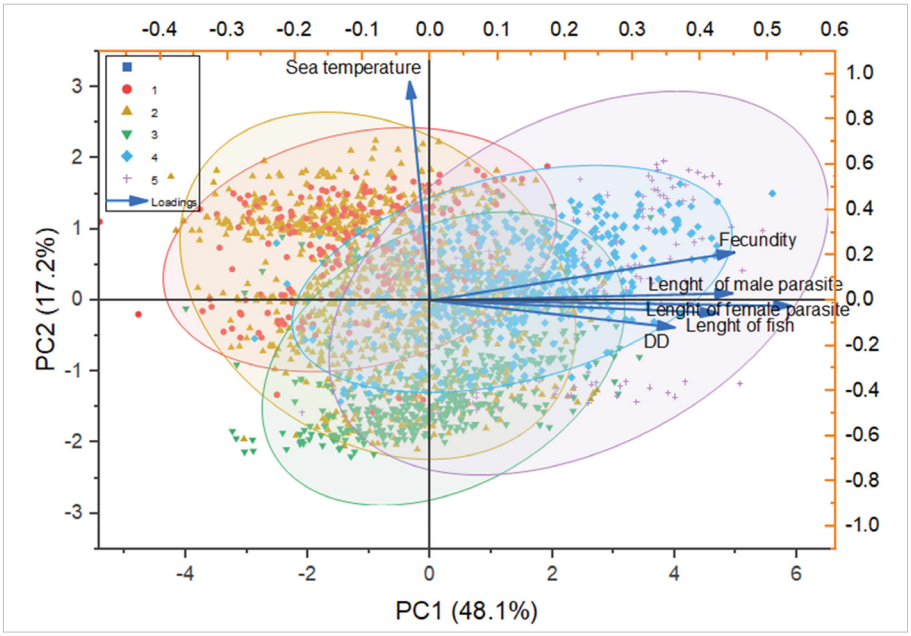


Figure 6 PCA biplot describing the distribution and relationships among measured parameters and DD groups

Slika 6. Biplot analize glavnih komponenata (PCA) s prikazom raspodjele i međuodnosa mjerenih parametara i DD skupina

Source: Author's own work using IBM SPSS Statistics

suggesting that biological size and reproductive traits explain most of the variability among samples. The blue points and purple plus clusters (representing the 4 and 5 DD groups, with the highest DD values) are positioned on the positive side of PC1 (Figure 6), clearly grouping with the vectors for fish length, male parasite length, female parasite length, fecundity, and DD, indicating that they are associated with increasing DD.

Their proximity to these loadings indicates a strong positive association with host size and reproductive parameters. In particular, the purple plus cluster lies further along the directions of the fecundity and length vectors, suggesting higher reproductive output and larger morphological traits than in other groups. The samples in the purple plus cluster have the highest DD values (Figure 6). This distribution confirms that biological size, reproduction-related variables, and DD values are the primary drivers separating these clusters from the remaining samples.

4. DISCUSSION / *Rasprava*

Intensive fish farming along the Mediterranean coasts creates ideal conditions for the proliferation of parasites with direct life cycles [26]. Understanding parasite biology enhances the management of parasitic infections and the sustainability of aquaculture by optimising treatments, supporting biological control, and reducing environmental impact [19-20]. Despite its economic importance to European sea bass farming, data on the reproductive output of the parasite *C. oestroides*, such as age at first maturity and fecundity by size and age, are lacking.

Temperature influences both fish growth and parasite development [27]. It affects host-parasite interactions, with rising temperatures expected to impact outbreaks [28-29]. Climate change may accelerate maturation and increase reproductive output in isopods [29-30]. The sea temperature range of 13-25 °C during this research matches that reported in prior data for the Adriatic Sea [31]. Fish fry are stocked year-round, but cold-season stocking grows more slowly and takes longer to reach vaccination size. At the same time, they are exposed to *C. oestroides* infestation, but the parasite takes many more days to reach sexual maturity than it does during fry transfer to sea cages in the warm season. Because the relationship between fish growth and parasites is complex, it's preferable to track growth and development under farm conditions using DD rather than relying on current temperature. In this study, DD was applied to estimate the timing of first sexual maturity and fecundity during the early cultivation phase.

Although the parasite likely originated from wild fish populations [12], given the long history of the disease at the investigated farms, we consider farmed fish to be the main source of pulli II larvae within the farm, influencing the health of newly arrived fish. The parasite prevalence across all examined fish was 0.71%, similar to that observed in previous studies from the same farm [22]. The highest prevalence among samples in this study was 4.8%. The sampling method was the same, and the prevalence reflects the efficacy of the applied measures. Removing parasitised fish during vaccination of the entire sea bass population in the first year of farming is likely to have less effect than antiparasitic treatments, but reinfection under farm conditions is expected in both cases [22]. Results suggest that the mechanical removal method would certainly be even more efficient if the fish were vaccinated earlier. The main losses from pulli II *C. oestroides* infestation are in fish under 20 grams [12-13, 15]. Therefore, prompt mechanical removal is essential to decrease reproductive pressure.

While all samples contained parasites, mature females were found in 70.8% of samples. Observed female maturity was in the range of 1873-6869 DD. This corresponds to approximately 75 days at 25 °C to 150 days at 13 °C. The proportion of mature females was lower than the 88-90% gravid females reported in previous studies from June to August [11]. The lower proportion of mature females in this study could be due to parasite age and to the different methodology. In this study, we defined mature females as those carrying larvae with pigmented eyes, whereas previous studies included females carrying eggs [11]. Additionally, in water, locating a male is essential for rapid sexual maturation, so male size becomes an important factor [31]. In the parasite pair with the immature female, the average female length was 21 mm, and the average male length was 9 mm. In the parasite pair with the mature female, the average female length was 24 mm, and the average male length was 11 mm. The parasitic pair may colonise the fish simultaneously, or the male may colonise later. Such complex situations cannot be predicted under the conditions of collecting data from breeding. The median length of both parasites, including the pairs with immature and mature females, increased with DD, and the growth between the sexes was synchronised.

The average fecundity was 91, with a broad range of 7 to 327 larvae with pigmented eyes. A prior study involving a smaller sample of smaller females reported 124 pulli I and 83 pulli II [15]. When fecundity is divided into five DD clusters, there is also a clear relation between fecundity and DD. The significance of early mechanical removal becomes evident; only one sample with a mature female had fewer than 2000 DD. Fish length was moderately positively correlated with mature female length, male length, and fecundity, as previously reported for *C. oestridis* and other isopod parasites, indicating that larger hosts support more developed and more fecund parasites [15, 33-35]. Female length affects fecundity [18], which may explain why fecundity in our study is lower than reported in previous studies [11-12]. In our study, a strong positive relationship was observed between female length and fecundity. A positive correlation between parasite size and fecundity has been reported [11]. It is also possible that male size is crucial for fecundity in the isopod *Ceantiella isopus*, where females mated with small males showed lower fecundity than those mated with large males [32].

Implementing an integrated control strategy that combines antiparasitic methods promotes optimal fish production and minimises the risk of resistance [20]. Our study's results can improve integrated control strategies by providing more accurate estimates of optimal treatment timing. The sample size was large, but some limitations of the study must be acknowledged. The time of the parasite's infestation is unknown. Degree days are calculated from the settlement of fish in the sea cage. Nevertheless, the results clearly indicate a possible maturity window for DD. Also, an increase in female length and parasite fecundity with increasing DD was observed. Even if the parasite persists in the mouth without killing the host, removing it helps reduce the reproductive pressure of *C. oestroides* on farms. The efficiency of the mechanical removal method could be enhanced if fish were vaccinated earlier. Moreover, understanding how the removal process during

vaccination reduces parasite incidence can be applied to other related parasites, thereby helping to decrease parasite pressure on both farmed and wild fish.

Future research should address fecundity in older age categories of European sea bass and the presence of seasonal fluctuations in fecundity to improve estimates of the parasite's reproductive potential and farm population models.

5. CONCLUSION / *Zaključak*

This study uses degree-days as a predictive tool for the epidemiology of *C. oestroides* infection in cage-farmed European sea bass in the central Eastern Adriatic Sea. It showed that degree days (DD) are a useful predictive tool for estimating the timing of first reproductive maturity and fecundity of *C. oestroides* in cage-farmed European sea bass. Mature females were predominantly observed above approximately 1800 DD, while fecundity, parasite size, and host size increased progressively with increasing DD values. The relationship between DD, parasite size, and fecundity suggests that DD could be a useful tool for predicting the development and reproductive activity of parasite populations. This study provides practical implications for aquaculture management, including the optimisation of vaccination timing, mechanical removal, and antiparasitic treatments before the parasite reaches reproductive maturity. Health management should recognise climate change as a major environmental challenge and incorporate thermal-time models to improve predictions of parasite infections and treatment outcomes, accounting for the parasite's temperature-dependent development and life cycle.

Author Contribution: Conceptualisation, S. Č., M. K., and D. M.; Methodology, S. Č., M. K., and D. M., and T. M.; Software, T. M.; Validation, S. Č., T. M., B. M.; Formal Analysis, S. Č. and T. M.; Investigation, S. Č., M. K., D. M., T. Š., Š. F., M. J.; Resources, S. Č., M. K.; Writing – Original Draft Preparation, S. Č. and T. M.; Writing – Review & Editing, S. Č., T. M., B. M and M. K.

Funding: This study was funded by the European Union, through the NextGenerationEU program under the TIDE project (IP-UNIZD 2025, MT 27015). This publication reflects only the authors' views and does not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Conflict of interest: None.

Acknowledgements: The authors would like to thank the Cromaris R&D team for technical support and assistance during this research. We also thank the Ministry of Science, Innovation and Technological Development of Serbia for its support (451-03-68/2026-14/200024).

Ethical Statement: The EU legislation regarding fish farming operations does not require an ethical review beyond those already included in the EU Directive 98/58 and the recommendation of the Standing Committee of the European Convention on the Protection of Animals kept for Farming Purposes (https://www.coe.int/t/e/legal_affairs/legal_co-operation/biological_safety_and_use_of_animals/Farming/Rec%20fish%20E.asp; accessed on 15 January 2026).

Research was conducted under standard production conditions and in full compliance with animal welfare regulations applicable to aquaculture in the Republic of Croatia and the European Union.

Acknowledgement of AI or AI-assisted tools use: We have not used AI or AI-assisted technologies to prepare this work.

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