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Spawning Migration Period of European Eel (*Anguilla anguilla* L. 1758) in Güllük Lagoon (Türkiye) Inferred from CPUE Analysis

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Abstract: The European eel (*Anguilla anguilla*) is a critically endangered catadromous fish species. Determining the timing of their spawning migration is crucial for effective conservation of this species. In this study, we aimed to identify the spawning migration period of European eels caught in Güllük Lagoon (Muğla, Türkiye). For this purpose, catch per unit effort (CPUE, defined as the number or biomass of eels caught per fishing gear per unit time) was calculated for yellow and silver individuals. Monthly changes in CPUE were analyzed using fyke nets, with samples collected by local fishermen between February 2022 and January 2023. The results revealed that CPUE for silver eels reached its peak in November, and silver individuals were present in the catch composition until the end of January 2023, indicating that the spawning migration likely occurs between November and February. Furthermore, CPUE values declined by almost tenfold compared to those reported in a similar study conducted in the region approximately 15 years ago. These findings confirm the migration period and also highlight the increasingly critical status of this local subpopulation, underlining the urgency of conservation actions.

Keywords

- Stock
- Decline
- Migration
- Monitoring
- Catch per unit effort

1. INTRODUCTION

The European eel (*Anguilla anguilla* Linnaeus, 1758) is listed as critically endangered (CR) on the IUCN Red List (Pike et al., 2020). The European Council has issued regulations to improve *A. anguilla* stocks (European Council, 2007). This species is panmictic (Als et al., 2011), semelparous, and facultative catadromous, migrating to the marine environment of the Sargasso Sea for reproduction (Tzeng et al., 2000; Daverat & Tomás, 2006; Prigge et al., 2013). European eels begin their lives after reproducing in the Sargasso Sea. The larvae, known as Leptocephali, migrate to coastal areas aided by ocean currents before reaching continental waters. The leptocephali transform into glass eels while their bodies elongate. The glass eels then enter inland waters through estuaries and lagoons, growing through several metamorphoses. The stage at which they become residents of inland waters is called yellow eels. These eels spend most of their lives in these areas before metamorphosing into silver eels and migrating back to the Atlantic Ocean for reproduction (Tesch, 2003). *A. anguilla* has a wide distribution, covering coastlines from the entire European continent to Great Britain, the western coasts of Russia, North Africa, the Aegean Sea, and the Mediterranean (Fishbase, 2025). Their route to the Mediterranean begins at the Strait of Gibraltar, where they enter the Mediterranean and reach the European coasts (Lecomte-Finger, 1992), extending to the shores of Türkiye. As sea temperatures rise, they migrate to inland waters (Küçük et al., 2005; O'Leary et al., 2022).

Historical data on populations distributed across the European continent indicate that eel stocks in these regions were once quite high and that European eels were considered a primary food source among freshwater fisheries in many European countries (Ringuet et al., 2002). However, it has been determined that European eel populations began to decline across their distribution range from the 1980s onward (Dekker, 2003; Dekker & Casselman, 2014), and are now estimated to be only about 1% of their former numbers (Correia et al., 2018; ICES, 2023). The causes of this decline include various factors such as changes in climate and ocean currents, pollution, fishing, the presence of migration barriers (dams and hydroelectric power plants), habitat loss, deterioration of water quality, diseases, and overfishing (Dekker, 2003; Dekker & Casselman, 2014). Many eel sub-population have been severely affected by the construction of dams and hydroelectric power plants. Over the past 30 years, sharp declines in recruitment and migration (escapement) rates of European eels to the sea have accelerated scientific efforts to assess their long-term conservation status. With the accumulation of scientific data on stock declines, this species has been recognized as critically endangered since 2008 (Jacoby & Gollock, 2014; Ammar et al., 2021).

The Mediterranean coastal area is a significant part of the continental habitat (Cataudella et al., 2015). From southern Europe to the North African coast, the Mediterranean basin is suggested to significantly contribute to the global European eel population (Dekker, 2003). European eel populations across different habitats are currently viewed as subpopulations of the global panmictic stock. Therefore, the recovery of this global stock largely depends on the contributions of Southern European and North African nations within the Mediterranean Basin. For the European Commission's conservation strategy (EC No 1100/2007) to be effective in these regions, it is essential to gain comprehensive insights into the life history traits of European eels.

This study aimed to determine the timing of European eel spawning migration by analyzing monthly variations in Catch-per-Unit Effort (CPUE) data in Güllük Lagoon.

2. MATERIALS AND METHODS

2.1. Study area and sampling activities

The study was conducted in the Güllük Lagoon, located in the south of the Aegean Sea, on the eastern side of Güllük Bay (Figure 1). The lagoon comprises a 250-hectare wetland and an 800-decare lake area, with a maximum depth of 150 cm (Alparslan, 2013). Two sluice gates were installed in the straits connecting the lagoon to the sea to facilitate lagoon fishing. Currently, the operation of the lagoon fishery is the responsibility of the Muğla Provincial Directorate of Agriculture and Forestry. However, the lagoon fishery has not been operational for two years.

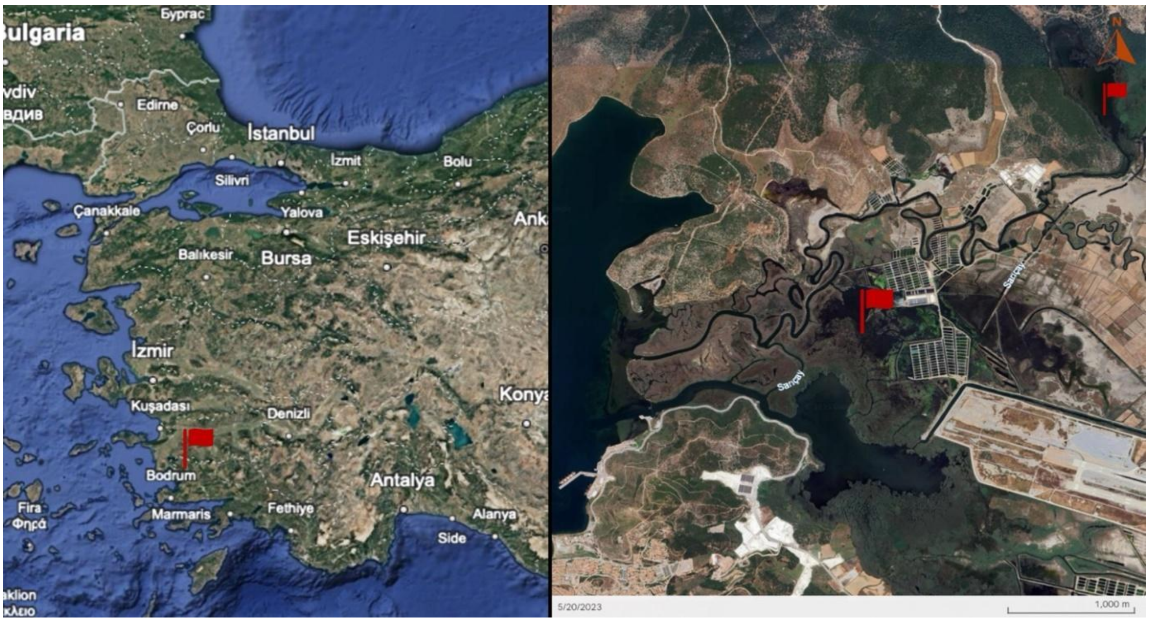

Figure 1. Study Area.

Sampling methods were selected according to the guidelines on fish sampling methods specified by the Ministry of Agriculture, Forestry, and Water Affairs for European eel sampling. FAO's Eel Sampling Methods (FAO, 1980) were also considered. The methods used in the study by Küçük et al. (2005) were also applied to fish sampling. To ensure that the samples represented the local eel subpopulations, two different sampling locations were selected: one in Güllük Lagoon and the other in Limni Lake where the part of the sub-population inhabits the area (Table 1).

Table 1. The specifications of sampling locations.

Sampling Points	Coordinates		Altidude (m)	Distance to Eustary (m)	Water Characteristics
1	37°15'43"N	27°37'47"E	0	1850	Brackish
2	37°16'42"N	27°39'09"E	1,61	7900	Brackish

This study used 15 mm mesh-sized fyke-nets in sections with a maximum water depth of 1.5 meters at Güllük Lagoon. The fyke nets were connected in series to allow for a single-entry and unidirectional flow based on the physical characteristics of the region. Caught eels were collected from fyke nets by fishermen over several consecutive days (4-6 days). The total weights of the eels was measured, and the number of silver and yellow eels was recorded for each operation.

Various methods have been developed to determine the life stages of the European eels. Observing changes in skin coloration is one of the most commonly used approaches (Pankhurst, 1982; Durif et al., 2005; Durif et al., 2009). In this method, the body coloration—either yellow or silver—indicates whether an eel has reached reproductive maturity. The yellow eels exhibited an overall yellowish body coloration. In contrast, silver eels display a distinct lateral line, whitish abdominal region, and dorsal area that appears grayish, smoky, or nearly black.

2.2. Data Analysis

Catch per unit effort (CPUE) refers to the quantity of European eel (by weight in kg) caught using a single fishing gear (fyke net, dip net, or electroshocker) over a unit of time (minute, hour, day) (MacNamara & McCarthy, 2014). During the calculations, the total fish weight (W, kg) and total fish count (N, individuals) captured during the sampling period (4–6 days) were divided by the sampling duration (t, days) to determine the daily catch of all fyke nets combined. The obtained results were then divided by the number of fyke nets (P) to estimate the daily eel catch per fyke net (kg or individuals) (Equations 1 and 2). These calculations were performed separately for all individuals, silver eels, and yellow eels. Commercial fishermen collected European eel catch data monthly for over 12 months, from February 2022 to January 2023. At this stage, the phenotypic characteristics were examined to differentiate between silver and yellow eels. Using the collected data, CPUE calculations were performed monthly based on the following formula, with separate evaluations conducted for silver eels, yellow eels, and the entire sample.

$$CPUE\ (kg) = \frac{\frac{W}{t}}{P} \quad (1)$$

$$CPUE\ (number) = \frac{\frac{N}{t}}{P} \quad (2)$$

Statistical analysis was performed after the normality of the data was tested using the Shapiro-Wilk test. Normally distributed data were analyzed using the one-way ANOVA or the t-test with the Bonferroni test. Levene's test was used to analyze the equality of variances. Non-parametric data were analyzed using the Mann-Whitney U test. Statistical analyses were performed using SPSS version 22.0, and Microsoft Office 365 (Excel) was used for data analysis or to create graphs.

3. RESULTS

The calculation of Catch Per Unit Effort (CPUE) involves collecting monthly data on the number, weight, and developmental stages of the fish caught by fishermen. The identification of silver and yellow eels was based on the phenotypic characteristics reported by the fishermen. CPUE calculations were conducted separately for the silver and yellow eels. Monthly differences were not statistically significant for the total CPUE in quantity (N, individuals) (ANOVA: Single-factor, *df*: 11, *F*: 1.97, *p*: 0.053) and weight (W, kg) (ANOVA: Single-factor, *df*: 11, *F*: 1.64, *p*: 0.118). The monthly quantities of silver and yellow eels showed significant differences for all months (t-test with Bonferroni, *df*: 10, *t-crit*: 1.81-2.27, $p < 0.05$ or Mann-Whitney U test, *U*: 0, *Z-score*: 2.35 – 4.20, $p < 0.05$) except December 2023 (Mann-Whitney U test, *U*: 3.50, *Z-score*: 1.31, *p*: 0.096).

The number of silver individuals (Ns) did not significantly differ until November (Pairwise Mann-Whitney tests, $p > 0.05$), then peaking in November (Kruskal-Wallis Test, *df*: 11, *p*: 0.0001), and then declined from December onward (Pairwise Mann-Whitney tests, $p > 0.05$). The number of yellow European eels (Ny) differed in various months (Jan-Feb, Jan-Aug, and Jan-Nov, One-way ANOVA, $df = 11$, $F = 3.24$, $p = 0.002$). The weight-based data (Ws and Wy) exhibited similar trends. The only interesting significance for the weights of silver eels (Ws) was observed between January and the other months except for October and December; the silver eels yielded more in January than in the other months (One-way ANOVA, $df = 11$, $F = 5.21$, $p = 0.00002$).

Statistically, significant differences were observed between silver and yellow individuals throughout the year except in December. In November, this statistical difference supported the dominance of silver eels in the sample (t-test with equal variances, $df = 10$, $t\text{-}crit = 1.81$, $p = 0.003$), whereas yellow eels were dominant in the remaining months, yellow eels were dominant. It should also be mentioned that there was no dominance in December between Silver and Yellow eels, which can be assumed to be approximately equal in proportion to stock (Mann-Whitney U test, $U = 4$, $z\text{-}score = 1.15$, $p = 0.12$). The CPUE data were calculated separately for each fishing event to standardize the CPUE values due to multiple fishing operations within the same month. The monthly averages of the data are presented in Tables 2 and 3, respectively.

Table 2. Catch per unit effort (CPUE) data based on count. CPUE values represent the individual eels caught per fyke-net per day. The number of eels was given as a monthly average.

	Fyke-net (n)	Fishing Days	N	Ny	Ns	CPUE Ny	CPUE Ns	CPUE N
February	5 ± 0.00	6 ± 0.00	2 ± 1.22	2 ± 1.22	-	0.07 ± 0.04	-	0.07 ± 0.04
March	16 ± 0.00	4 ± 0.00	9 ± 2.62	8 ± 3.08	1 ± 0.71	0.13 ± 0.05	0.02 ± 0.01	0.14 ± 0.04
April	16 ± 0.00	4 ± 0.00	11 ± 2.55	11 ± 2.55	-	0.17 ± 0.04	-	0.17 ± 0.04
May	16 ± 0.00	4 ± 0.00	11 ± 1.70	10 ± 1.89	1 ± 0.22	0.16 ± 0.03	0.02 ± 0.01	0.17 ± 0.02
June	16 ± 0.00	4 ± 0.00	8 ± 1.87	8 ± 1.87	-	0.13 ± 0.03	-	0.13 ± 0.03
July	22 ± 1.58	4 ± 0.00	10 ± 6.67	10 ± 6.67	-	0.12 ± 0.08	-	0.12 ± 0.08
August	13 ± 1.41	4 ± 0.00	4 ± 3.08	4 ± 3.08	-	0.07 ± 0.05	-	0.07 ± 0.05
September	13 ± 1.58	4 ± 0.00	7 ± 4.85	7 ± 4.85	-	0.13 ± 0.09	-	0.13 ± 0.09
October	32 ± 20.07	3 ± 0.71	12 ± 5.26	11 ± 4.74	1 ± 1.00	0.12 ± 0.05	0.01 ± 0.01	0.13 ± 0.06
November	90 ± 0.00	4 ± 0.00	27 ± 5.23	6 ± 6.76	21 ± 6.93	0.02 ± 0.02	0.06 ± 0.02	0.08 ± 0.01
December	90 ± 0.00	4 ± 0.00	17 ± 4.42	11 ± 2.55	6 ± 6.16	0.03 ± 0.01	0.02 ± 0.02	0.05 ± 0.01
January	86 ± 4.47	5 ± 0.58	22 ± 8.50	18 ± 7.05	4 ± 3.83	0.04 ± 0.01	0.01 ± 0.01	0.05 ± 0.01

n: Number of Fyke-nets per operation, N: Number of eels per operation, Ns: Number of Silver eels per operation, Ny: Number of yellow eels per operation.

Table 3. Catch per unit effort (CPUE) data based on weight. CPUE values represent the kilograms of eels caught per fyke-net per day. The weight of eels was given as a monthly average.

	Fyke-net (n)	Fishing Days	W (kg)	Wy (kg)	Ws (kg)	CPUE Yel (g)	CPUE Sil (g)	CPUE W (g)
February	5 ± 0.0	6 ± 0.0	1.00 ± 0.7	1.00 ± 0.7	-	33.33 ± 23.5	-	33.33 ± 23.5
March	16 ± 0.0	4 ± 0.0	2.25 ± 0.8	2.00 ± 0.8	0.25 ± 0.2	31.25 ± 13.1	3.91 ± 2.5	35.16 ± 11.4
April	16 ± 0.0	4 ± 0.0	3.10 ± 0.6	3.10 ± 0.6	-	48.44 ± 9.4	-	48.44 ± 9.4
May	16 ± 0.0	4 ± 0.0	3.00 ± 0.2	2.73 ± 0.2	0.27 ± 0.2	42.62 ± 2.3	4.26 ± 2.4	46.88 ± 3.9
June	16 ± 0.0	4 ± 0.0	2.90 ± 1.2	2.90 ± 1.2	-	45.31 ± 18.8	-	45.31 ± 18.8
July	22 ± 1.6	4 ± 0.0	3.18 ± 1.9	3.18 ± 1.9	-	37.41 ± 24.0	-	37.41 ± 24.0
August	13 ± 1.4	4 ± 0.0	1.28 ± 0.9	1.28 ± 0.9	-	24.11 ± 15.4	-	24.11 ± 15.4
September	13 ± 1.6	4 ± 0.0	1.13 ± 0.8	1.13 ± 0.8	-	21.01 ± 13.2	-	21.01 ± 13.2
October	32 ± 20.0	3 ± 0.7	5.05 ± 3.0	4.63 ± 2.7	0.42 ± 0.5	48.44 ± 28.7	4.39 ± 4.5	52.82 ± 31.4
November	90 ± 0.0	4 ± 0.0	18.00 ± 5.3	4.00 ± 2.9	14.00 ± 6.3	11.11 ± 8.2	38.89 ± 17.5	50.00 ± 14.9
December	90 ± 0.0	4 ± 0.0	10.25 ± 3.9	6.63 ± 0.9	3.63 ± 4.1	18.40 ± 3.8	10.07 ± 11.4	28.47 ± 11.0
January	86 ± 4.0	5 ± 0.6	10.20 ± 3.7	8.35 ± 2.9	1.85 ± 1.8	18.84 ± 4.0	4.14 ± 4.4	23.20 ± 6.6

n: Number of Fyke-nets, W: Weight of total eels, Ws: Weight of silver eels, Wy: Weight of yellow eels

As expected, significant differences were projected in the CPUE Sil (g) calculation, similar to Ns and Ny (Kruskal-Wallis test, $df = 11$, $p = 0.0002$). These significant differences were observed in November compared with the other months. In contrast, yellow eels were yielded low in November with 11.11 ± 8.18 CPUE Yel (g) (Single-factor ANOVA, $df = 11$, $F = 2.44$, $p = 0.02$). These data also show significant changes in stock life stages depending on a certain time during the year. CPUE data regarding the number of individuals (CPUE Ns and CPUE Ny) caught during the year showed significant differences in certain months, especially CPUE Ns in November (Kruskal-Wallis test, df = 11, p = 0.0002). CPUE Ny differed significantly between the various months (One-way ANOVA, $df = 11$, $F = 4.64$, $p = 0.0001$). In this analysis, there was a pattern of seasonal changes in the CPUE Ny. The periods of April-May (spring) and Sep-Oct (autumn) significantly differed from the period of Nov-Dec-Jan (Tukey HSD, $df = 48$, $q\text{-}crit = 4.86$, $p < 0.05$).

The changes in the composition of the silver and yellow eels within the total sample are shown in Figure 2. During the summer months, the population was almost entirely composed of yellow eels, whereas in winter, the proportions of silver and yellow eels shifted inversely.

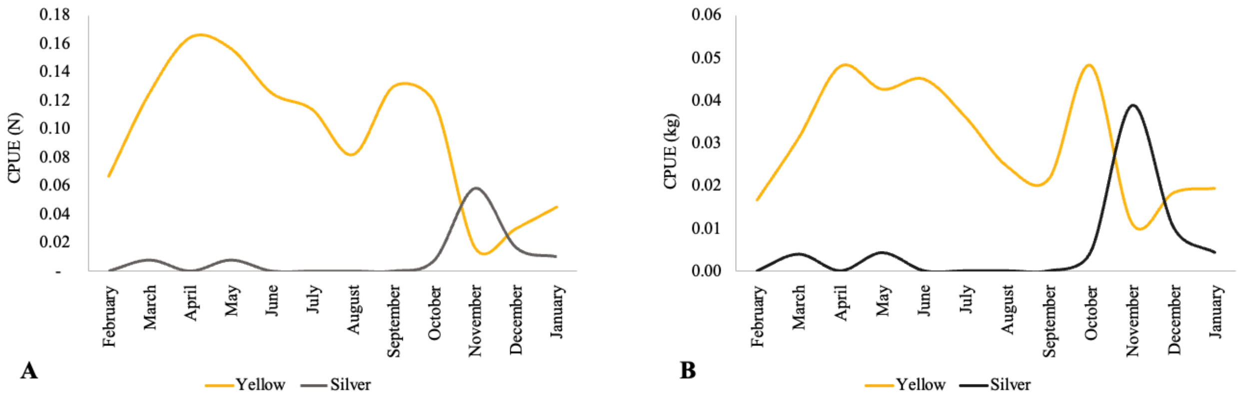

Figure 2. Catch per unit effort (CPUE) based on the **(A)** number of individuals (CPUE N) and **(B)** weight (CPUE W).

4. DISCUSSION

The global population of European eels (Anguilla anguilla) has experienced a very high decline in recent years (Pike et al., 2020). Many studies conducted in different eel habitats throughout Europe used the catch per unit effort (CPUE) method to determine the stock status and general trends of the population (van Gemert et al., 2024; McDowell et al., 2025).

In this study, the CPUE values calculated for European eels in the Güllük Lagoon were considerably lower than the results of studies conducted in other habitats. The CPUE values of European eels in the Wimereux and Liane estuaries in France were reported as 2.4-9.0 individuals/fykenet/day and 2.7-10.5 individuals/fykenet/day, respectively (Denis et al., 2022). In two different lakes in Ireland, very high CPUE values (5-6.1 kg/fykenet/day and 26.7-39.2 individuals/fykenet/day) were calculated (Grennan & McCarthy, 2013). The CPUE data recorded in Estonia showed that it was below 0.02 individuals/fykenet/day in 2014 (Bernotas et al., 2016). In the same study, the CPUE values in terms of weight for 2013 were reported as 0.05-0.1. As a result of longline fishing (100 hooks), CPUE data of 1 kg/hookset/day were reported in Estonia, according to 2012 data (Bernotas et al., 2016). The individual silvery production quantities of the restocked European eel subpopulation in the Shannon River (Ireland) were analyzed (MacNamara & McCarthy, 2014). In this study, it was determined that the estimated silver eel catch amount for the years 2009, 2010 and 2011 could be 68.6 t (1.62 $kg.ha^{-1}$), 62.7 t (1.48 $kg.ha^{-1}$) and 61.6 t (1.45 $kg.ha^{-1}$), respectively.

Studies on sub-populations, which are relatively high in European habitats compared to Turkish habitats, are currently focused on various protective factors such as restocking, monitoring and reducing the effects of migration barriers. However, the fact that historical records are insufficient in Türkiye shows that the studies carried out are important even in terms of obtaining basic data such as CPUE. The calculations of CPUE (516.75 g/fykenet/day) specific to eel in Güllük Lagoon were first carried out by Erdem and Cerim (2011) between 2007-2008. In a study conducted by us in the same lagoon 15 years after the publication of this study, the CPUE calculations for European eels resulted in an annual average of 53.00 g/fyke net/day. According to these results, the European eel in Güllük Lagoon may have decreased by 90% on average. Erdem and Cerim (2011) did not share information on fishing dates, sample numbers or sampling frequencies. However, in a study conducted in 2015, it was reported that the total catch landed in Güllük Lagoon was 110 kg per hectare over 110 years (Tosunoğlu et al., 2017). However, no specific information was provided for eels in this study. Therefore, an in-depth examination of the eel subpopulation in the region could not be performed. When other studies conducted in Türkiye were examined, it was understood that regional data on eel subpopulations were obtained in recent years. In a study conducted by Balkan (2016), as a result of sampling on the Karamenderes River (Çanakkale, Türkiye) and Kırkgözler Channel (Çanakkale, Türkiye), the values of European eel were 7.2% (%80.00 abundance) in spring, 4.6% (%2.74 abundance) in summer and 4.4% (%30.19 abundance) in autumn. However, the CPUE (%13.80 abundance) data for the winter season were not shared in their study. In a study conducted on the north-eastern Mediterranean coast (Asi River, Hatay, Türkiye), which is the limit of the distribution areas of European eels, seasonal CPUE calculations were performed. According to the results of this study, the daily catch per fyke net was approximately 11 in winter, 8 in spring, 12 in summer, and 11 in autumn (Demirci et al., 2020). The most comprehensive study conducted in Türkiye on the monitoring of European eels is the study published by Yalçin-Özdilek & Özdilek, (2020). In this study, Eel Monitoring Areas (EMA) were planned to develop an eel fishery management system in Türkiye.

CPUE values can sometimes provide important predictions about the period when European eel subpopulations perform spawning migration. In particular, changes in the dominance of eel life stages in the subpopulation over time can be used to determine the migration times. A study conducted in the Shannon River reported a positive correlation between the spawning migration times of silver eels and decreasing water temperatures (MacNamara & McCharthy, 2014). Similar inferences were made using CPUE in the Thames River subpopulation, and silver eels were reported to reach their highest levels at the end of the autumn season (Steele et al., 2018). In the case of the Güllük Lagoon, changes in monthly yellow and silver eel catches observed throughout the year also indicate that spawning migration occurred between November and February in this region.

The approximately tenfold decrease in the European eel (*A. anguilla*) subpopulation in Güllük Lagoon and its surroundings in recent years may be due to multiple potential threats. Unreported fishing has been observed to be widespread in the region, which may be putting pressure on the population (Dekker, 2003; Yalçın-Özdilek and Özdilek, 2020). Furthermore, intensive aquaculture activities carried out on land can cause high nutrient transport into the lagoon via the Sarıçay Stream, altering the trophic structure. While this process may increase the food supply for eels in the short term, it can potentially lead to negative long-term effects such as eutrophication, oxygen depletion, and the accumulation of chemical pollutants (Piria et al., 2014; Demirci et al., 2020). Pharmaceuticals and chemicals used in aquaculture can also accumulate in the lagoon ecosystem and have toxic effects on fish. Furthermore, the ongoing manipulation of irrigation and discharge channels, the widening of stream beds, and the loss of coastal vegetation may have restricted eel habitat. All of these factors may be among the primary reasons for the significant decline in CPUE values in the region. However, more comprehensive and long-term monitoring studies are needed to confirm these relationships and definitively demonstrate their impacts (Bernotas et al., 2016; Denis et al., 2022; MacNamara and McCarthy, 2014; Yalçın-Özdilek and Özdilek, 2020).

5. CONCLUSION

Comprehensive studies on European eel stocks, subpopulations, habitats, diets and biology are increasing day by day in Türkiye. In parallel, the traceability of stock status at regional and seasonal levels is increasing. In particular, the fact that CPUE data are relatively easy to follow makes this method important for determining both temporal and spatial changes in stocks. In addition, by evaluating temporal changes in terms of life stages, we can determine whether there has been a change in migration times of eels. Thus, in taking protection measures, especially in fishing regulations, the widespread use of the CPUE will provide a great advantage for future regulations.

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DATA AVAILABILITY STATEMENT

Data supporting the findings of the present study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

Fiction: EB, FK; Literature: EB, FK; Methodology: EB, FK; Performing the experiment: EB; Data analysis: EB; Manuscript writing: EB, Supervision: FK. All authors approved the final draft.

ETHICAL STATEMENTS

This study was conducted with the approval of Animal Experiments Local Ethics Committee of Isparta University of Applied Sciences (Date: 05.08.2021, No: 003).

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